WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Quality and Fate of Fish Hatchery Effluents During the Summer Low Flow Season

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Quality and Fate of Fish Hatchery Effluents During the Summer Low Flow Season

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ABSTRACT

A study of freshwater fish hatcheries was conducted by the Washington State Department of Ecology during the 1988 summer low flow period. Hatchery effluents showed significant increases in temperature, pH, suspended solids (total and volatile), ammonia, organic nitrogen, total phosphorus, and chemical oxygen demand. Wastewater discharge sometimes caused violation of state water quality standards; impacts were exacerbated by poor dilution. Hatchery nutrient loads equalled or exceeded receiving water loads; effects of enrichment were most evident in oligotrophic waters. Benthic invertebrates sensitive to organic waste were often replaced by more tolerant forms in the vicinity of hatchery outfalls. Recommendations include: 1) provide solids sedimentation as a minimum wastewater treatment strategy; 2) revise state pollutant discharge permit requirements; and 3) monitor phosphorus in freshwaters receiving hatchery effluents.

INTRODUCTION

The freshwater culture of trout and salmon is an expanding enterprise in Washington State. At present, about 80 state, 15 federal, and 5 tribal hatcheries produce salmonids in support of sport and commercial fisheries. An unknown number (50?) of hatcheries are privately-owned, rearing fish for sale to the public. While some of these aquaculture facilities do not actually hatch fish eggs on site, the term "hatchery" will be used here to collectively describe any fish hatching or rearing operation.

Liao (1970a) was among the first to report of water quality degradation associated with salmonid culture. Hatchery waste products include uneaten food, fecal matter, soluble metabolites (e.g., ammonia), algae, parasitic microorganisms, drugs, and other chemicals. Fish hatchery effluents thus may deliver nutrients, solids, and potential toxicants to the receiving environment.

Hatchery wastewater discharge is regulated under the National Pollutant Discharge Elimination System (NPDES). In Washington State, the Department of Ecology administers NPDES permits for state and private hatcheries; federal and tribal discharges are regulated by the U.S. Environmental Protection Agency (EPA). NPDES permits are required only of larger facilities--i.e., those exceeding 20,000 pounds of production per year or 5,000 pounds of feed use per month. Smaller facilities can be issued NPDES permits if they violate state water quality standards or significantly contribute to pollution. In addition, state waste discharge permits may be required of smaller commercial hatcheries.

Existing hatchery discharge permits issued by Ecology are outdated and often do not reflect available and reasonable pollution control technology. Typically, effluent limits are specified for flow and settleable solids. Some permits also limit suspended solids, including a few which require 85 percent removal of such solids from cleaning wastewaters. The Water Quality Program of Ecology is now reviewing these limits with the intent of developing a general hatchery permit for statewide application. A Memorandum of Understanding between Ecology and the Washington Fish Growers Association commits Ecology to develop the general permit by September 30, 1989.

In response to program and regional requests for current data on hatchery discharges, the Surface Water Investigations Section of Ecology studied 20 state- and privately owned facilities in Washington during 1988. Survey objectives were:

1. Characterize effluent quality at freshwater fish hatcheries statewide during the summer low flow period.

2. Assess receiving water impacts caused by fish hatchery discharge during summer low flow.

3. Compare discharge quality and receiving water effects to findings reported in the literature.

4. Evaluate point source control requirements for freshwater fish hatcheries in Washington.

Field activities were scheduled for the summer low flow season in order to assess receiving water impacts during the period of least dilution. This design precluded the sampling of state hatcheries at maximum production, which typically occurs in spring. However, snowmelt runoff also peaks in spring and thus likely mitigates instream effects. Consequently, little information loss was expected by restricting sampling to summer. As added compensation, sampling was biased toward private fish hatcheries, which usually maintain high production throughout the year.

Hatchery waste loads were expected to be variable due to differences in facility design and size, production rates and timing, quantity and quality of source water, hydraulic retention time, fish species and age, feed types and rates, maintenance practices (e.g., cleaning), and effluent treatment. To assess this variability, sampling effort was spread over many hatcheries. In exchange, sampling frequency at individual sites was often minimal.

METHODS

Sampling Design

Sampling was conducted at 20 freshwater fish hatcheries statewide between June and September 1988. Hatchery locations are shown in Figure 1. Sites were concentrated in western Washington due to the relatively large number of hatcheries located there. A description of each hatchery is provided in Table 1.

Two types of monitoring were employed. The first, intensive surveys, consisted of grab and composite sampling of hatchery influent and effluent; receiving water sampling upstream and downstream of hatchery discharge; and an upstream/downstream assessment of benthic macroinvertebrate communities. The second type of monitoring consisted solely of grab sampling of influent and effluent at a single point in time. Intensive surveys were performed at five of the 20 hatcheries, four of which were privately owned.

An inventory of samples collected and analyses performed is given in Table 2. Note that several samples were collected in support of special studies--i.e., release events, cleaning wastewaters, and settling efficiencies. About 10 percent of samples were replicates. Hatchery managers were given 0-24 hours' notice prior to sampling.

Composite samples were taken using iced ISCO automatic samplers which collected a 200 mL sample every half-hour for 24 hours. Where possible, flows were measured as head heights at weirs; otherwise, cross-channel measurements were taken with a Swoffer or Marsh-McBirney current meter. Other field measurements were temperature (mercury thermometer), pH and conductivity (Beckman meters), and dissolved oxygen (azide-modified Winkler titration).

Samples for laboratory analysis were iced immediately and shipped within 24 hours to the EPA/Ecology Laboratory in Manchester, Washington. Sample containers, processing, and analysis conformed to EPA (1983), APHA *et al.* (1985), and Huntamer (1986).

Benthic macroinvertebrates were sampled in receiving waters using rapid bioassessment techniques similar to those proposed by Plafkin *et al.* (1988). Biota were collected by kicking a square meter of riffle substrate for 30 seconds; dislodged organisms were captured in a D-frame net (600 um mesh) positioned immediately downstream. To facilitate comparisons between sites, similar habitats (e.g., depth, velocity, shading) were sampled. In addition, replicate samples were taken at every site.

After collection, each biota sample was placed in a water-filled pan. Over a ten-minute span, live organisms were removed with forceps and preserved in 70 percent ethanol. Categorical abundance of unpicked forms was estimated by eye. Invertebrates were later identified to family using the keys of Pennak (1978) and Merritt and Cummins (1984).

Data Analysis

As an initial exploratory technique, hatchery and receiving water quality data were examined using stem-and-leaf plots. Two features stood out: 1) most variables were not normally distributed, but instead were skewed right; and 2) left-censored values (less than detection limit) were present. These features are typical of water quality data sets and, in combination with small sample size, they invalidate the use of standard parametric statistical tests (Gertz 1978; Helsel 1987). Consequently, only nonparametric procedures were applied during data analysis.

Nonparametric statistics are based on data ranks, as opposed to actual values. Thus the median, rather than the mean, was used as a measure of central tendency. The median is the middle value of a series of values arranged (ranked) in order of magnitude. Likewise the interquartile range, rather than the standard deviation, was used as a measure of dispersion. The interquartile range is calculated as the difference between the 1st and 3rd quartiles--i.e., those values at the 25th and 75th percentiles of the ranked data set (the median, or 2nd quartile, is at the 50th percentile).

For ease of analysis, hatchery data sets were reduced so that each facility was represented by one influent and one effluent sample. Where multiple samples were collected, the composite sample was selected as most representative. In the absence of a composite sample, the median of a series of grab samples was used. Left-censored values were included at one-half the detection limit. Net changes in water quality were calculated as the difference between influent and effluent values. Loads were calculated by multiplying concentration by flow by 5.3936 (a units conversion factor).

The Wilcoxon signed-rank test, a nonparametric alternative to the paired t-test, was used to test for differences between influent and effluent water quality. Parameters showing statistically significant changes were included in a Spearman rank correlation analysis to explore their interrelationship. The Mann-Whitney test, a nonparametric alternative to the standard t-test, was used to test for differences in net water quality changes between state and private hatcheries.

Macroinvertebrate collections were tabulated semi-quantitatively, with categories of rare, present, common, and abundant denoting occurrences of 1, 2-4, 5-25, and greater than 25 organisms per sample, respectively. Rare occurrences coupled with taxon absence in the replicate sample were regarded as chance events and ignored in subsequent analyses.

Two-way indicator species analysis (TWINSPAN) was used to reduce the complexity of the macroinvertebrate data set. TWINSPAN simultaneously performs an ordination (reciprocal averaging) and a classification (polythetic divisive clustering) to produce an ordered taxa-by-site table which groups similar sites together (Hill 1979). Advantages of TWINSPAN over traditional agglomerative clustering methods are discussed by Gauch (1982) and Pielou (1984).

Four indices of macroinvertebrate community structure were also calculated. Taxa richness, defined as the number of taxa present in a sample, was reported two ways: 1) total, which included all forms; and 2) EPT, which included only taxa belonging to the pollution-sensitive orders of Ephemeroptera, Plecoptera, and Trichoptera. A Similarity of Dominants index was calculated by applying the Jaccard (1912) similarity coefficient to common and abundant (i.e., dominant) taxa:

$$\text{Similarity of Dominants} = C/(R + A - C)$$

where R = Number of dominant taxa at the reference site
A = Number of dominant taxa at the 'affected' site
C = Number of dominant taxa common to both sites.

A final index, the Community Loss Coefficient (Courtemanch and Davies 1987), was calculated as:

$$\text{Community Loss} = (R - C)/A$$

where R = Number of taxa at the reference site
A = Number of taxa at the 'affected' site
C = Number of taxa common to both sites.

RESULTS

Quality Assurance

Raw water quality data are presented in Appendices A (hatcheries) and B (receiving water). Several items concerning data quality assurance were noteworthy:

- Some flow values were estimates based on pumping rates or measurements taken at improperly-sized weirs.

- The Beckman pH meter failed at Aberdeen Trout Hatchery, resulting in loss of pH data for that site.

- One conductance value and two solids values were unexplainable outliers and thus were omitted from subsequent data analyses.

- Total kjeldahl nitrogen consists of ammonia and organic nitrogen fractions. Independently-determined ammonia values exceeded kjeldahl values in 10 of 106 samples collected. Six of the 10 were at Sea Farm of Washington, where highly variable conductance was observed due to periodic inputs of salt (NaCl) for treatment of fish. Because inorganic solids and salt interfere with the kjeldahl test (APHA *et al.* 1985), these six kjeldahl values were considered invalid and omitted from further data analyses. Chloride in salt interferes with the COD test, so the six corresponding COD values at Sea Farm were also rejected. The aberrant kjeldahl value at Spokane Trout Hatchery may have been caused by inorganic solids interference, thus it too was omitted. The remaining three kjeldahl results in question were within 0.01 mg/L of the reported ammonia values; consequently they were considered acceptable, with organic nitrogen assumed to be absent.

- Nitrate-nitrite data from July 12-13 were reported as estimates due to laboratory quality control discrepancies; these values were not used in subsequent data analyses.

- During intensive surveys, no consistent temporal shifts in water quality were observed: grab and composite results generally agreed. However, composite effluent COD and BOD data at Domsea Farms were considerably elevated relative to grab samples. Since all samples were collected at the downstream end of three large settling ponds in series, overnight shock loads were highly unlikely. Lacking a plausible explanation, the composite COD and BOD data were omitted from later data analyses. Composite COD data at Issaquah Salmon Hatchery were also higher than grab results, but the differences were minor and the data regarded as acceptable.

Replicate samples of effluent and receiving water were collected to assess sampling and analytical variability. Similarity of each replicate pair was measured by computing the relative percent difference (RPD), defined as the difference between two replicates divided by their mean. Results were expressed with box plots (Figure 2).

Box plots graphically depict the distribution of a series of data points (McGill *et al.* 1978). The box itself represents the interquartile range (IQR), with the median displayed as a line within the box. Vertical lines project above and below the box to the maximum and minimum data values; values which exceed the IQR by 1.5 times are plotted individually.

Figure 2 shows the distribution of RPDs for replicated variables. Flows were replicated thrice, all other parameters tenfold. Variability in replicate sampling was generally low. COD, SS, and TKN outliers were products of substituting one-half the detection limit for censored values. The apparent high variability of TSS replicates was an artifact of significant digits. For example, replicate values of 1 and 2 mg/L yield an RPD of 67 percent. In reality, all TSS replicate pairs were within 1 mg/L, except for a cleaning event replicate which produced an RPD of 120 percent (1 and 4 mg/L).

Wastewater Characteristics

Summary statistics for 16 of 20 hatcheries surveyed are presented in Table 3. Data from the four remaining facilities were excluded as nonrepresentative of typical operations (e.g., cleaning in progress). Data from Tokul Creek Hatchery was not characteristic of the entire effluent, but was included as representative of rearing ponds.

Statistically significant increases were observed for temperature, pH, suspended solids (both total and volatile), ammonia, organic nitrogen, total phosphorus, and COD. Net loads calculated for five variables of interest showed similar gains. Net changes in BOD could not be assessed for lack of influent measurements. However, BOD and COD were strongly correlated (Spearman rank $r = 0.88$, $p < 0.01$).

Temperature increases in fish hatcheries are attributed to solar warming. Elevated pH may stem from plant growth within hatcheries (discussed further below). Suspended solids are largely derived from uneaten food and fish feces. Ammonia is an excretory product of fish metabolism. Organic nitrogen and phosphorus are feed components. Increases in COD are likely caused by increases in volatile (i.e., organic) suspended solids.

Although the median net change in nitrate-nitrite was zero, statistical testing indicated a significant decline occurred between influent and effluent. Rank correlation analysis revealed a marked association between nitrate-nitrite and two other variables, namely pH and flow (Figure 3). Significant nitrate-nitrite losses were observed only at hatcheries with pH increases and flows under 6 cfs. Both of these factors implicate uptake of nitrate-nitrite by plants: photosynthesis raises pH, while low flows favor algal/macrophyte attachment and phytoplankton retention.

Dissolved oxygen losses within fish hatcheries were expected due to fish respiration and decomposition of organics; however, no statistically significant changes were observed. This occurred because oxygen losses at some facilities were balanced by photosynthetic gains and/or use of aerators at others. A maximum loss of 12.2 mg/L was observed at Domsea, where oxygen injection increased influent concentrations to 22.9 mg/L (203 percent saturation). A maximum gain of 4.2 mg/L was observed at a 'U-fish' operation which featured a series of highly productive lakes (oxygen is a by-product of photosynthesis).

Water quality parameters which changed significantly from influent to effluent were subjected to rank correlation analysis to further explore their interrelationship. Two additional variables, flow and fish density, were also included. Results are displayed in Table 4. Strong positive correlations were observed between fish density, suspended solids (total and volatile), and nutrients (ammonia, organic N, and total P). Flow was negatively correlated with most variables, reflecting the influence of dilution.

Water quality at state and privately owned hatcheries is compared in Table 5. Private facilities had significantly higher net changes in temperature, TSS, ammonia, organic N, and total P. These differences were expected due to the higher fish densities ('LbsCfs') and lower flows at private hatcheries. Ammonia and organic nitrogen loads were also higher at private facilities, but differences in TSS and total P loads were statistically non-significant.

Three state hatcheries were sampled during cleaning operations. Statistical comparison of water quality between these facilities and other state hatcheries showed only TSS (net change) to be different ($p = 0.05$). Non-significance in remaining variables is attributed to dilution because only a limited portion of each hatchery was being cleaned at any one time. Nonetheless, the strength of cleaning wastewater is considerable. Individual cleaning waste streams were sampled at state facilities in Yakima and Aberdeen; both evidenced very high solids, nutrients, and oxygen demand (Appendix A).

Settling of whole effluent was provided at two privately owned hatcheries, Sea Farm and Domsea. Grab samples collected before and after settling showed a reduction in suspended solids, but sample size was small (Appendix A). A 'sewage fungus' community, likely dominated by the bacterium *Sphaerotilus natans*, was present in the Sea Farm effluent channel upstream of the settling basin, but was absent downstream. The reason for this is unclear, but loss of organic matter due to sedimentation is one possibility.

Juvenile anadromous salmonids are often released from state hatcheries through the draining of rearing ponds. Water quality samples were collected during such a release at Naselle Salmon Hatchery. Samples taken before, at the midpoint, and near the end of pond draining showed dramatic increases in solids, organic N, total P, and COD (Appendix A). As pond depth decreased, fish became more crowded, which increasingly disturbed accumulated sediments. Also, influent flow continued throughout the release, exerting a scouring effect as the pond shallowed. Remaining sediments were later removed for disposal on land.

<u>Receiving Water Quality</u>

Four streams were surveyed to assess the effects of hatchery discharge on receiving water quality (Figure 4). Results are tabulated in Appendix B. Significant findings are presented below.

Scatter Creek

Scatter Creek, located in Thurston County near the town of Rochester, is 21 miles in length and tributary to the Chehalis River. Two privately owned fish hatcheries, Sea Farm and Domsea Farms, discharge effluent to the creek. Both rely on wells for water supply. Local residents reported that the creek went dry in summer before the hatcheries began operating. Streamflow is now perennial.

The receiving-water-to-effluent dilution ratio at the upstream hatchery is 1:3. Effluent discharge from the downstream hatchery yields an ultimate dilution of 1:8. Thus both ground water and wastewater quality strongly influence the character of Scatter Creek. For example, stream temperatures fell and nitrate-nitrite levels rose due to ground water (well) inputs. Meanwhile, instream ammonia, organic N, and total P concentrations were elevated by wastewater inputs.

Scatter Creek is rated a Class A (excellent) waterbody by Ecology (WAC 173-201). Fish hatchery discharge did not cause violations of state water quality standards. Nutrient inputs probably stimulate plant growth in the creek, but upstream agricultural activities may also contribute to eutrophication (defined as elevated nutrient supply and related productivity enhancement).

Cinebar Creek

Cinebar Creek, a tributary to Mayfield Lake, is located in Lewis County near the community of Cinebar. The stream is about five miles in length and drains a recently logged watershed. Cascade Trout Farm diverts most of the creek into a series of aerated earthen ponds. Hatchery effluent is returned to the stream at a dilution ratio of 1:8 (creek:effluent).

Cinebar Creek is rated a Class AA (extraordinary) waterbody. Hatchery discharge violated several water quality standards (WAC 173-201). Temperatures taken at noon indicated a 1.7°C increase, which is above the allowable gain of 1.2°C. The pH shift exceeded the permissible change of 0.2 unit; mass balance of hydrogen ions showed that the 0.3 unit drop in pH was hatchery-induced. The dissolved oxygen standard was also violated, with levels falling below the standard of 9.5 mg/L. Suspended solids and nutrients rose, though applicable standards are lacking. The downstream depletion of ammonia and concurrent increase in nitrate-nitrite is indicative of instream nitrification.

Canyonfalls Creek

Canyonfalls Creek, located in Pierce County near the town of McMillin, is tributary to the Puyallup River. Stream length is three miles, the upper two being forested. The entire creek is diverted through a privately owned broodstock facility, Trout Springs. Effluent is discharged into a steep canyon which drops 300 feet in elevation over 1/4 mile.

Canyonfalls Creek is rated a Class A (excellent) waterbody. Because there is no dilution of effluent, water quality standards must be met at the hatchery outfall. The allowable temperature change of 1.6°C was violated, a consequence of solar warming in the long series of raceways which constitute the hatchery. Suspended solids and nutrients also increased, with downstream nitrification again evident. COD levels were elevated by hatchery wastes, but this demand was probably counteracted by discharge into a turbulent cascade.

Ammonia concentrations at the hatchery outfall were among the highest seen during the entire study. Total ammonia consists of two species, ammonium (NH_4^+) and un-ionized ammonia (NH_3). The latter form is toxic to aquatic life. The proportion of un-ionized ammonia increases with increasing temperature and pH. In Canyonfalls Creek, un-ionized ammonia toxicity would occur at total ammonia concentrations of about 1.8 mg/L (EPA 1986); effluent ammonia levels were well below this threshold.

Issaquah Creek

Issaquah Creek is located in the town of Issaquah (King County). The stream is 17 miles in length and flows into Lake Sammamish. Issaquah Creek was the only receiving water survey which involved a state hatchery discharge.

Issaquah Salmon Hatchery borders the creek, with raceways on one bank and two rearing ponds on the other. Half of Issaquah Creek is diverted into the raceways, yielding an effluent dilution rate of 1:1. Rearing pond water is drawn from the creek downstream of the raceway outfall, thus a portion of the raceway effluent is reused.

Issaquah Creek is rated a Class A (excellent) waterbody. Slight increases in suspended solids and nutrients were observed, but no water quality standards were violated. This finding was expected in light of reduced fish loading at the hatchery during summer months.

The preceding results demonstrate that receiving water effects were more pronounced when dilution was poor and effluent was discharged to an oligotrophic watercourse (i.e., one with low nutrient supply and consequent low productivity). Several violations of state water quality standards were observed. Nutrient standards are largely unavailable at present, but the eutrophication potential of hatchery effluents merits further consideration.

Effects of hatchery discharge on receiving water nutrient levels are illustrated in Figure 5. Hatchery effluents clearly elevated instream concentrations of kjeldahl (ammonia + organic) nitrogen and total phosphorus. Figure 6 compares nutrient loads of hatcheries and receiving waters. In all cases, hatchery loads equalled or exceeded upstream loads. Load differences were most dramatic at the two relatively pristine creeks, Cinebar (Cascade Trout) and Canyonfalls (Trout Springs). Note that the receiving water load at Domsea Farms (Scatter Creek) derives largely from the upstream discharge of Sea Farm, hence the cumulative nutrient load is substantial.

The growth of algae and other plants in freshwater ecosystems is usually limited by availability of phosphorus; nitrogen limitation can occur in highly enriched freshwaters (Welch, 1980). Hatchery phosphorus loads may be placed in better perspective by expression as population equivalents of domestic wastewater. The average phophorus load in biologically treated sanitary wastewater is estimated to be 0.006 pounds per capita per day (Clark *et al.* 1977). Thus hatchery discharges to Scatter Creek provided a phosphorus load equivalent to a secondarily treated sewage discharge from a community of 2300 people. Similarly, phosphorus loads to Cinebar, Canyonfalls, and Issaquah Creeks corresponded to sewage effluents from communities of 900, 1300, and 300, respectively.

Elevated phosphorus loading may lead to excessive plant growth in receiving streams. Nutrient export to downstream lakes and estuaries could cause or contribute to algal blooms in those systems. Deleterious effects of nuisance plant growths may include: 1) dissolved oxygen depression due to plant respiration or decomposition; 2) pH increases due to photosynthesis (un-ionized ammonia toxicity is more prevalent at higher pH); 3) changes in the aquatic food web; 4) impairment of aesthetic values owing to surface scums and other proliferative growths; and 5) alteration of the taste and odor of domestic drinking water supplies. In these instances, control of plant growth is imperative and can be achieved through reduction in phosphorus loading.

Biological Effects

Benthic macroinvertebrate communities were sampled to assess the biological health of streams receiving fish hatchery effluents. Invertebrates were selected because they are relatively long-lived and immobile, hence they would integrate the variability of hatchery waste discharges over time. Two impacts were postulated: 1) a conventional pollutant effect caused by organic and nutrient inputs; and/or 2) a toxic pollutant effect related to un-ionized ammonia discharge or intermittent chemical usage.

Macroinvertebrate collections are presented in Appendix C. Invertebrates within the hatchery effluent plume (i.e., before complete mixing) were sampled at both Scatter Creek (RM 8.0 and 6.4) and Cinebar Creek (RM 1.65). Benthic communities were not sampled at Canyonfalls Creek due to lack of comparable upstream and downstream habitat.

TWINSPAN results are given in Table 6. The tree-like dendrogram below each taxa-by-site table illustrates the similarity between sampling stations. Similar sites are located on the same 'branch' of the tree, while dissimilar sites occupy different branches. Note that replicate samples typically showed close similarity.

At all three streams, communities below hatchery outfalls were different from communities located upstream or further downstream. In Scatter Creek, this was particularly true for the upstream hatchery, Sea Farm (RM 8.0). In Cinebar Creek, invertebrates below the hatchery outfall (RM 1.65) were markedly different from those above. (Cinebar Creek was the only intensive study stream with a 'clean' substratum above the outfall and luxuriant periphyton growth below.) Despite relatively good dilution and low waste strength, invertebrates in Issaquah Creek were also affected by hatchery wastewater discharge (RM 3.0).

Several taxa appeared sensitive to hatchery waste discharges, including chloroperlid, leuctrid, and perlid stoneflies; heptageniid and leptophlebiid mayflies; brachycentrid caddisflies; and elmid beetles. These forms are largely intolerant of organic pollution (Hilsenhoff 1988). Taxa enhanced by hatchery effluents were flatworms, leeches, and aquatic earthworms; chironomid, simuliid, and tipulid flies; dytiscid beetles; and snails, especially planorbids. These forms likely benefit from surplus foods of hatchery origin (either directly, as with organic solids, or indirectly, via nutrient stimulation of primary productivity).

Four indices of community structure were calculated to further characterize benthic assemblages (Table 7). In general, total taxa richness increased below hatchery outfalls, but richness of taxa sensitive to organic pollution (EPT) declined. However, downstream recovery of EPT richness was observed in all three creeks. The Similarity of Dominants index was particularly noteworthy for Cinebar Creek, where only seven percent of dominant upstream taxa maintained their dominance below the point of hatchery discharge.

The Community Loss Coefficient is predicated on the notion that increases in total taxa richness are not necessarily detrimental to the benthic community (Courtemanch and Davies 1987). Index values increase, indicating harm, as taxa from the reference site are lost; recruitment of new taxa partially compensates for lost forms. As expected, community loss was greatest in Cinebar Creek.

In summary, benthic macroinvertebrate communities experienced moderate change in response to hatchery effluents. Some pollution-sensitive taxa were eliminated, with an equal or greater number of tolerant forms replacing them. Impacted communities had largely recovered within a short distance downstream. Changes in community structure are attributed to organic and nutrient loading rather than the action of un-ionized ammonia or other chemical toxicants.

DISCUSSION

A review of available literature indicated much of the recent study of fish hatchery effluents has been concentrated in Europe. Alabaster (1982) evaluated water quality changes at 38 European fish farms, noting reduced oxygen and increased solids, nutrients, and oxygen demand. Parallel results were observed at salmonid farms in the United Kingdom (Solbe 1982). In the United States, Liao (1970a,b), Hinshaw (1973), and EPA (1974) also reported degradation of waters passing through fish culture facilities.

Net changes documented by the above investigators were typically higher than those detected in the present work. One possible reason for this is use of mean, rather than median, values. In positively skewed data sets, the mean is usually larger than the median due to the influence of outliers. A second possibility is survey timing. The current study was performed during the summer low flow period, when state hatcheries are lightly loaded. If only privately owned hatcheries are considered, net changes become more comparable.

The literature concerning nitrate changes within fish hatcheries is conflicting. EPA (1974) reported nitrate losses within fish hatcheries and surmised, as in the present work, that algal uptake was responsible. However, Parjala *et al.* (1984) observed no change in nitrate concentrations between influent and effluent. Further, Liao (1970b) and Solbe (1982) documented net increases in nitrate, probably from fish feed, though nitrification may play a role. Hence the fate of nitrate within a hatchery may be linked to the level of photosynthetic activity within the facility.

Fecal coliform bacteria live in the intestines of warm-blooded animals and thus may indicate the presence of disease-causing microorganisms. Trust and Sparrow (1974) isolated fecal coliform from the gut of freshwater salmonids, but they believed the fish were only transient carriers of ambient forms. EPA (1974) reported an absence of fecal coliform in the gut and feed of cultured trout, but noted their presence in source water. Niemi and Taipalinen (1982) observed slight increases in fecal coliform through fish farms and suggested that bacterial growth may occur in fish intestines and/or hatchery sediments. Later, Niemi (1985) again found minor fecal coliform increases at fish farms, but the contamination was attributed to bird excrement in runoff water.

A number of investigators have documented receiving water quality degradation caused by hatchery wastewater discharge (Bodien 1970; Hinshaw 1973; Bergheim and Selmer-Olsen 1978; Alabaster 1982; Korzeniewski *et al.* 1982; Solbe 1982). Effects were variable, but included oxygen depression, solids deposition, and nutrient enrichment. These studies and the current work indicate that the degree of impact is a function of quality and quantity of both effluent and receiving water.

Munro *et al.* (1985) evaluated effects of salmon hatchery discharge on selected streams in nearby British Columbia. They found elevated ammonia and total phosphorus downstream of hatchery outfalls, with corresponding increases in periphyton production. However, these effects were localized and no instances of gross pollution were observed. As in the present study, changes ranged from enrichment to mild degradation.

Szluha (1974) reported a seven-fold increase in periphyton production rates below a fish hatchery on the Jordan River, MI. While speculating on potential benefits to higher trophic levels (e.g., game fish), Szluha was concerned about long-term effects of nutrient loading to downstream Lake Michigan. Heinonen (1984) also detected increased periphyton production below a hatchery, even though physical and chemical water quality appeared unchanged.

Several investigators recorded the occurrence of 'sewage fungus' in periphyton communities exposed to hatchery effluent (Hinshaw 1973; Alabaster 1982; JRB Associates 1984; Munro *et al.* 1985). Bahls and Bahls (1974) used the autotrophic index to detect a shift in periphyton composition from autotrophs (producers) to heterotrophs (consumers) following hatchery discharge. Munro *et al.* (1985) saw differences in periphyton species composition above and below hatcheries, but shifts from autotrophy to heterotrophy were not evident.

Salmonid culture is ideally suited to oligotrophic waters, yet ironically these same waters are most susceptible to nutrient enrichment. One proposed eutrophication remedy is reduction of phosphorus levels in feed to an amount required for optimum growth (Ketola 1982; Wiesmann *et al.* 1988). Ketola *et al.* (1985) began testing low phosphorus diets after eutrophication of a Michigan lake by hatchery effluent led to an NPDES permit limit on hatchery phosphorus loading. They developed an economical feed that provided 80-99 percent of normal growth while reducing phosphorus discharge by 38-56 percent.

The response of stream invertebrates to hatchery effluents reported here has been observed elsewhere. Bodien (1970) saw less diversity but increased abundance below a hatchery outfall in Oregon. Hinshaw (1973) studied several Utah streams and found enrichment of benthic communities downstream of hatchery discharges. Pollution-tolerant forms showed marked increases in abundance, with slight increases noted for pollution sensitive taxa. In most cases, partial recovery occurred within 0.2 mile downstream. JRB Associates (1984) measured reduced diversity and richness among benthic communities in an Idaho stream with three hatchery discharges. Only minor impacts were recorded in a nearby stream with two hatcheries. Munro *et al.* (1985) documented increased abundance of invertebrates tolerant of organic pollution in British Columbia streams receiving hatchery wastes. Sensitive forms appeared unaffected, however.

Invertebrate sampling during this study failed to evidence toxicity linked to chemical use within fish hatcheries. Chemicals may be used in fish culture for several purposes, including control of parasites and disease; cleaning and disinfecting; and, to a lesser extent, alteration of flesh color and growth enhancement (hormones). Chemicals may be administered via injection, but they are more commonly incorporated into feed or added directly to water.

A list of chemicals which have been used in aquaculture is provided in Table 8. The list should be regarded as provisional because the approval status of some chemicals may be under review (e.g., astaxanthin and chloramine-T are expected to be registered shortly). The list is probably not complete, but at least the more commonly encountered compounds are included. Use of specific trade names is not intended as an endorsement; other manufacturers may market comparable products.

Use of pharmaceuticals and pesticides in fish culture is regulated by the Food and Drug Administration (FDA) and EPA, respectively. Regulations apply to all life stages, including eggs. Permitted uses and application rates are given on product labels; misuse of chemicals is illegal. Due to low economic incentive, few sponsors seek FDA or EPA approval for use of their products on fish. As a result, fish growers sometimes use non-approved compounds in violation of federal regulations. Both FDA and EPA have recently stepped up enforcement in this arena.

Chemical usage in fish hatcheries is not likely to cause toxicity in the receiving environment if applicators adhere to recommended doses and stagger treatments (e.g., one raceway at a time) to increase dilution. Still, two chemical/disease issues remain: 1) chemical persistence in receiving waters; and 2) transfer of non-endemic diseases to wild stocks. Jacobsen and Berglind (1988) documented the persistence of oxytetracycline in sediments beneath marine net pens. Concentrations were sufficient to exert antibiotic effects for months after application, with unknown impact on natural microbial communities. Leong and Fryer (1980) demonstrated that large quantities of IHN and IPN virus were released into the environment during outbreaks at fish hatcheries. By inference, this finding suggests the potential for non-endemic disease transmittal to native fish in the receiving water. However, neither of these issues should be cause for concern in properly managed facilities.

Cleaning wastewaters account for much of the total waste load from salmonid hatcheries (Liao 1970b; EPA 1974; KCM 1974). Cleaning operations may be active (brushing, vacuuming) or passive (self-cleaning by hydraulics or sweeping arms). Frequencies range from daily to annually (e.g., rearing ponds are usually cleaned only once, following drawdown for release or harvest). Sedimentation of cleaning waste flows has proven an effective pollution control strategy at fish hatcheries (Hydroscience 1978; McLaughlin 1981). Due to high nutrient content, waste solids have potential value as fertilizer.

Federal regulation of hatchery waste discharge was initiated in 1972 with creation of the NPDES permit program (Harris 1981). However, national effluent guidelines drafted by EPA (1974) were never adopted. EPA later sponsored a study of Idaho fish hatcheries in an effort to establish regional effluent limitations. Study findings demonstrated that hatchery effluent quality was best improved by one-hour settling of the entire flow or separate sedimentation of cleaning waste flows (JRB Associates 1984). Proposed limits on suspended and settleable solids discharge have since been incorporated into NPDES permits issued by EPA to Idaho fish hatcheries.

CONCLUSIONS

- Waters passing through fish hatcheries showed statistically significant increases in temperature, pH, suspended solids (total and volatile), ammonia, organic nitrogen, total phosphorus, and COD. Wastewaters generated during cleaning and pond drawdown were of considerable strength.

- Discharge quality during the summer low flow period was poorer at privately owned facilities due to higher fish loading and lower dilution rates. Fish loading at state hatcheries typically peaks in spring when increased snowmelt runoff enhances dilution and dispersion of wastes.

- Receiving waters showed elevated solids and nutrients downstream of hatchery outfalls. Violations of state water quality standards were observed for temperature, pH, and dissolved oxygen. Un-ionized ammonia was not present in toxic quantities.

- Hatchery nutrient loads often greatly exceeded upstream receiving water loads. Eutrophication effects were more pronounced when dilution was poor and receiving water quality was high. Significance of nutrient export to downstream lakes and estuaries was not evaluated, but nonetheless remains a major concern.

- Benthic macroinvertebrates showed moderate change in response to hatchery discharge. Forms sensitive to organic enrichment were often replaced by more tolerant organisms. Community structure usually recovered within a short distance downstream.

- Few chemicals have been registered for use in fish culture; consequently, illegal application of non-approved compounds may be widespread. Use of approved chemicals is not expected to cause receiving water toxicity if applicators follow label recommendations and stagger doses in space and time.

- Hatchery discharge permits issued by Ecology to date do not adequately address parameters of concern. Furthermore, many existing facilities fail to provide "all known available and reasonable" waste abatement measures required by state law (RCW 90.48).

- Previous studies have demonstrated that hatchery effluent quality may best be improved by sedimentation of waste solids. Settling may contribute to phosphorus load reductions because phosphates often exist in solids phase or are readily sorbed by organic particulates.

RECOMMENDATIONS

Ecology should develop a general hatchery permit applicable statewide. Effluent guidelines should be patterned after those adopted by EPA for use in Idaho. Specifically, sedimentation of waste solids should be a minimum treatment requirement for all freshwater hatcheries in Washington. Two options which appear to offer comparable waste treatment are clarification of whole effluent or off-line sedimentation of cleaning flows (Hydroscience 1978). Whole effluent should be allowed to settle at least one hour before discharge. Cleaning wastewater should be detained at least one day (batch-operation). Design of settling basins should: 1) minimize short-circuiting; and 2) provide for maintenance of treatment during sludge removal.

Proposed effluent limitations and monitoring requirements are outlined in Table 9. Flow limits are not provided, but should be set individually for each hatchery based on loading rates. Effluent limits for temperature and dissolved oxygen are not specified, but changes in these parameters should not cause violations of state water quality standards. The proliferation of 'sewage fungus' in receiving streams is an indication of gross organic pollution and thus constitutes an unacceptable impairment of environmental and aesthetic quality.

Monitoring results should be reported to Ecology monthly. The monthly report should also specify the pounds of fish on hand; pounds of food fed; type, quantity, and frequency of chemical usage; significant mortalities and cause; and a description of any irregular activities (e.g., pond draining for harvest or release).

Solids limits shown in Table 9 are attainable through adherence to best management practices (BMPs) and use of properly designed settling facilities (JRB Associates 1984). Several BMPs are noteworthy:

- Cleaning should be performed frequently enough to prevent solids washout and minimize leaching of nutrients from sediment to water.

- Vacuum pumps should be operated under 50 gallons per minute during cleaning to minimize homogenization of solids (Hydroscience 1978).

- Screened quiescent zones should be provided at the downstream end of raceways to enhance deposition of solids destined for off-line treatment (see JRB Associates [1984] for design criteria). Installation of raceway baffles may promote self-cleaning upstream of the quiescent zone (Boersen and Westers 1986).

- When working in ponds or raceways, care should be taken to avoid the resuspension and overflow of settled material.

- Dead fish and spawning or processing wastes should not be discharged to the receiving watercourse.

- Use of automatic feeders at timed intervals should be avoided to prevent excessive solids loading.

- Water reuse should be curtailed if receiving water dilution rates are low.

- Prior to release or harvest of fish in rearing ponds, accumulated solids should be removed to the extent possible. During drawdown, inflowing water should be diverted and drainage rate minimized. Drawdown should cease when 6-12 inches of water remain; the pond should be allowed to dry before sediments are removed for disposal on land.

- Fish should not be reared in sedimentation ponds.

- Drug and pesticide usage should be restricted to approved compounds. Prophylactic use of drugs and other chemicals should be avoided to prevent development of resistant microbial strains.

- Chemical treatments should be staggered in time and space to maximize dilution. Toxic chemicals like chlorine should be neutralized prior to discharge.

Salmonid culture is optimized in waters of superior quality, thus hatcheries are preferentially sited on oligotrophic rivers and streams. Unfortunately, these same waters are most sensitive to nutrient enrichment, particularly inputs of phosphorus. As a result, nutrient load reductions may be required to prevent excessive plant growth downstream of hatchery outfalls.

At present, neither state nor federal water quality standards contain a unilateral phosphorus criterion for control of nuisance plant growths. Mills *et al.* (1985) suggested that eutrophication problems were likely to occur when instream phosphorus concentrations surpassed 0.13 mg/L (given sufficient nitrogen). EPA (1986) proposed more stringent phosphorus problem thresholds: 0.05 mg/L in streams tributary to lakes or impoundments, and 0.10 mg/L in other flowing waters. EPA further recommended a limit of 0.025 mg/L within lakes and reservoirs; this criterion is presently enforced in the Spokane River at Long Lake (WAC 173-201).

To protect nutrient-sensitive drainages against eutrophication, Ecology should require fish culturists to periodically monitor receiving water phosphorus levels. At a minimum, monitoring should be performed once every five years during waste discharge permit renewal. Annual monitoring may be in order in high-quality ecosystems. Receiving water samples should be collected both upstream of the hatchery intake (or influence) and downstream of the outfall (after complete mixing of effluent and stream). Samples should be taken during the period of worst dilution, typically the summer low flow season.

Ecology should compare results of instream phosphorus sampling to the proposed EPA limits noted above. If a downstream value exceeds the threshold concentration, further investigation would be warranted. Additional nutrient sampling, dissolved oxygen and pH surveys, and/or periphyton growth plate studies may be needed to determine the nature and extent of eutrophication. In some streams, other factors may control nuisance plant growths, including temperature, light, substrate, or essential elements like nitrogen and carbon. Elsewhere, upstream sources may be more significant contributors of phosphorus (hence the rationale for collecting an upstream sample).

If additional work demonstrates a eutrophication problem owing to hatchery discharge, a limitation on phosphorus loading may be imposed. Phosphorus reductions could be achieved through reduced fish loading during critical periods (thereby increasing effective dilution); use of low-phosphorus feeds; decreased food wastage; and/or enhanced wastewater treatment.

Ecology should require a detailed water quality assessment when a proposed aquaculture facility is to be sited on an environmentally sensitive receiving water. The assessment should include an analysis of phosphorus loading similar to that described above. More stringent permit limitations may be prescribed when two or more hatcheries are to be sited on the same receiving stream.

The environmental impact of net-pen aquaculture in lakes and impoundments was not addressed in the present survey. A brief literature search revealed considerable potential for excessive solids and nutrient loading due to lack of water exchange (Penczak *et al.* 1982; Merican and Phillips 1985; Wisniewski and Planter 1987). Ecology should limit net-pen aquaculture in lakes pending further study and review.

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TABLES

Table 1. Descriptive data on Washington fish hatcheries sampled during the summer of 1988.

Facility	County	Design	Discharge Sampled	Species Reared*	Size on Hand	Pounds on Hand	Production Goal	Water Source	Receiving Water	Comments
Naselle Salmon Hatchery (WDF)	Pacific	Concrete raceways & ponds	Single pond	Chinook salmon	Juvenile	50,000	Smolt release	Naselle River	Naselle River	Pond at maximum loading; sampling included release event
Sea Farm of Washington, Inc.	Thurston	Circular fiberglass tanks	Entire facility	Atlantic salmon	Juvenile & brood-stock	40,000	Smolts to marine net-pens	Well	Scatter Creek	Wastewaters pass through small settling basin before discharge
Domsea Farms, Inc.	Thurston	Concrete ponds	Entire facility	Coho salmon	Juvenile & brood-stock	160,000	Smolts to marine net-pens	Well	Scatter Creek	Wastewaters pass through three settling ponds in series before discharge
Cascade Trout Farm	Lewis	Earthen ponds with concrete bottoms	Entire facility	Coho & Atlantic salmon	Juvenile & adult	65,000	Pan-sized coho & adult Atl. to market	Cinebar Creek	Cinebar Creek	Water reuse and aeration; cleaning wastewater applied to land
Puyallup Trout Hatchery (WDW)	Pierce	Concrete race-ways & ponds; rock-lined ponds	Entire facility	Rainbow, cutthroat, steelhead, brown, & brook trout	Juvenile	15,000	Juvenile, smolt, & adult releases	Clarks Creek	Clarks Creek	Limited water reuse
Trout Springs (Troutlodge, Inc.)	Pierce	Concrete raceways	Entire facility	Rainbow trout	Brood-stock	200,000	Egg sales	Canyon-falls Creek	Canyon-falls Creek	Water reuse and aeration; limited settling of some effluent; cleaning wastes to evaporation pond
Spokane Trout Hatchery (WDW)	Spokane	Concrete race-ways & ponds	All but 2 broodstock discharges	Rainbow, brook, & brown trout; grayling	Juvenile	45,000	Juvenile & adult releases	Springs	Little Spokane River	
George Adams Salmon Hatchery (WDF)	Mason	Concrete race-ways & earthen ponds	Entire facility	Chinook & coho salmon	Juvenile	35,000	Juvenile & smolt releases	Purdy Creek	Purdy Creek	
Steelhammer Salmon Farm, Inc.	Thurston	Concrete ponds & fiberglass tanks	Two of 4-5 discharges from site	Coho salmon	Juvenile	80,000 (entire facility)	Pan-sized to market	Well	Applied to land	Each outfall sampled drained 4 concrete ponds
Swecker Salmon Farm, Inc.	Thurston	Concrete & earthen ponds; aluminum tanks w/plastic liners	Largest of 2 discharges	Atlantic, chinook, & coho salmon; rainbow trout	Juvenile	125,000	Pan-sized to market or smolts to marine net-pens	Well	Applied to land	Some water reuse; cleaning wastes to evaporation pond; did not sample small portion of wastewater routed around lower ponds

Table 1. Continued

Facility	County	Design	Discharge Sampled	Species Reared*	Size on Hand	Pounds on Hand	Production Goal	Water Source	Receiving Water	Comments
Cowlitz Salmon Hatchery (WDF)	Lewis	Circular & modified Burrows ponds; kettles	Entire facility	Chinook & coho salmon	Juvenile	120,000	Juvenile & smolt releases	Cowlitz River	Cowlitz River	
Nisqually Trout Farm #1	Thurston	Earthen race-ways & ponds	Entire facility	Rainbow trout	Juvenile	10,000	Transfer to Nisq. Trout Farm #2	Springs	McAlli-ster Creek	Water reuse and aeration
Nisqually Trout Farm #2	Thurston	Gravel-bottom raceways & ponds	Entire facility	Rainbow trout	Juvenile	15,000	Pan-sized to market	Springs	Woodland Creek	Water reuse and aeration
Hood Canal Salmon Hatchery (WDF)	Mason	Concrete race-ways & ponds	Entire facility	Chinook & coho salmon	Adult returns & juve-niles	15,000	Smolt release	Finch Creek	Finch Creek/ Hood Canal	Limited water reuse
Yakima Trout Hatchery (WDW)	Yakima	Concrete race-ways & ponds	Single raceway	Rainbow trout	Juvenile	3,000	Juvenile & adult releases	Well	Bachelor Creek	Raceway near maximum loading; sampling included cleaning event
Trout Meadows Ranch	Yakima	Earthen ponds	Entire facility	Rainbow, cutthroat, brown, & lake trout	Juvenile & adult	Unknown	"U-fish"	Naches River	Applied to land	Seven ponds in series
Columbia Basin Trout Hatchery (WDW)	Grant	Concrete raceways	Entire facility	Steelhead, rainbow, & brown trout	Juvenile	35,000	Juvenile, smolt, & adult releases	Gloyd Springs	Gloyd Springs Creek	
Tokul Creek Trout Hatchery (WDW)	King	Concrete race-ways & earthen pond	Single pond	Steelhead trout	Juvenile	10,000	Smolt release	Tokul Creek	Tokul Creek	
Aberdeen Trout Hatchery (WDW)	Grays Harbor	Concrete race-ways & fiber-glass tanks	Lower 6 raceways	Cutthroat & steel-head trout	Juvenile	15,000 (entire facility)	Smolt release	Lake Aberdeen	Van Winkle Creek	Some water reuse in lower 6 raceways; also sampled cleaning waste abatement pond effluent
Issaquah Salmon Hatchery (WDF)	King	Concrete race-ways & ponds	Raceways and ponds separately	Coho salmon	Juvenile & a few adult returns	10,000 in raceways; 15,000 in ponds	Smolt release	Issaquah Creek	Issaquah Creek	About 50% of pond water is reused from raceways; cleaning wastewater to pollution abatement pond

* Chinook salmon = Oncorhynchus tshawytscha, coho salmon = O. kisutch, rainbow trout = O. mykiss (formerly Salmo gairdneri), steelhead trout = O. mykiss (anadromous), and cutthroat trout = O. clarki (formerly Salmo clarki); Atlantic salmon = Salmo salar, and brown trout = S. trutta; brook trout = Salvelinus fontinalis and lake trout = S. namaycush; and grayling = Thymallus arcticus.

Table 2. Sampling design for environmental assessment of Washington fish hatcheries during the summmer of 1988.

Survey	Date	Weather	Sample Type*	Parameter** Flow	Temp	pH	Cond	DO	TS	TNVS	TSS	TNVSS	SS	NH3	NO3	TKN	TP	COD	BOD	BM	Comments
Naselle Salmon Hatchery (WDF)	6/1	Drizzle	IG-1	-	X	X	X	-	X	X	X	X	X	X	X	X	X	X	-	-	Sampling restricted to one rearing pond
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
			EG-RE-2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Scatter Creek	7/12-15	Drizzle	RW-5R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	X	Two fish farms discharge to creek
Sea Farm of WA, Inc.			IG-2	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			MG-3	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			EG-4R	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	X	-	
			EC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	X	-	
Domsea Farms, Inc.			IG-2	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			MG-3	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			EG-4R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	X	-	
			EC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	X	-	
Cinebar Creek	7/19-20	Clear	RW-3R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	X	
Cascade Trout Farm			IG-3	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			IC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-3R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	X	-	
			EC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	X	-	
Puyallup Trout Hatchery (WDW)	7/26-27	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
			EG-CE-1R	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	X	-	
Canyonfalls Cr	7/26-27	Clear	RW-2	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	Entire creek flows through Trout Springs facility
Trout Springs			IG-3	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-3R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	X	-	
			EC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	X	-	
Spokane Trout Hatchery (WDW)	8/2	Clear	IG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	Sampled largest of 3 discharges from site
			EG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
George Adams Salmon Hatchery (WDF)	8/2	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Steelhammer Salmon Farm Inc.	8/2	Clear	IG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	Sampled largest 2 of 4-5 discharges from site
			EG-2	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Swecker Salmon Farm, Inc.	8/2	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	Sampled largest of 2 discharges from site
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Cowlitz Salmon Hatchery (WDF)	8/16	Drizzle	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-CE-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	

Table 2. Continued

Survey	Date	Weather	Sample Type*	Flow	Temp	pH	Cond	DO	TS	TNVS	TSS	TNVSS	SS	NH3	NO3	TKN	TP	COD	BOD	BM	Comments
				Parameter**																	
Nisqually Trout Farm #1	8/17	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Nisqually Trout Farm #2	8/17	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Hood Canal Salmon Hatchery (WDF)	8/17	Clear	IG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	
			EG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Yakima Trout Hatchery (WDW)	8/23	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	Sampling restricted
			EG-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	to one raceway
			EG-CE-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	
Trout Meadows Ranch	8/23	Clear	IG-1	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			EG-1	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
Columbia Basin Trout Hatchery (WDW)	8/24	Clear	IG-1	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
			EG-CE-1R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	
Tokul Creek Trout Hatchery (WDW)	8/24	Clear	IG-1	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	Sampling restricted
			EG-1	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	to rearing pond
Aberdeen Trout Hatchery (WDW)	8/30	Clear	IG-1	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	-	Sampled 1 bank of
			EG-2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	-	raceways (IG&EG) and abatement pond (EG)
Issaquah Creek	9/6-7	Over-cast	RW-4R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	X	Raceway effluent mixes with creek
Issaquah Salmon Hatchery (WDF) raceways			IG-2	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	upstream of rearing
			EG-2	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	pond intake. One of
			EC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	X	-	2 rearing ponds held only a few
Issaquah Salmon Hatchery (WDF) rearing ponds			IG-2	-	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	adults -- sampled it
			EG-3R	X	X	X	X	X	-	-	X	-	X	X	X	X	X	X	-	-	once (EG).
			EC-1	-	-	-	X	-	X	X	X	X	X	X	X	X	X	X	X	-	

* Numerals denote sample size; IG = Influent grab; EG = Effluent grab; RE = Release event underway; RW = Receiving water grab; R = Replicate(s) also taken; MG = Effluent grab upstream of settling pond; EC = Effluent composite; IC = Influent composite; CE = Cleaning underway.

** X = Sample or measurement taken; - = No sample.
Temp=Temperature; Cond=Specific conductance; DO=Dissolved oxygen; TS=Total solids; TNVS=Total non-volatile solids; TSS=Total suspended solids; TNVSS=Total non-volatile suspended solids; SS=Settleable solids; NH3=Ammonia-nitrogen; NO3=Nitrate-plus-nitrite-nitrogen; TKN=Total kjeldahl nitrogen; TP=Total phosphorus; COD=Chemical oxygen demand; BOD=Biochemical oxygen demand (5-day); BM=Benthic macroinvertebrates.

Table 3. Summary of wastewater quality at Washington fish hatcheries sampled during the summer of 1988. IQR = Interquartile range; n = sample size.

		Influent					Effluent					Net Change				
Parameter	Units	Median	IQR	Min.	Max.	n	Median	IQR	Min.	Max.	n	Median	IQR	Min.	Max.	n
Flow	cfs	--	--	--	--	--	8.2	5.2	2.0	14.6	16	--	--	--	--	--
Temperature	deg C	10.6	4.0	9.5	17.3	16	12.8	2.9	10.1	20.9	16	1.3 *	2.4	-0.4	3.6	16
pH	units	7.6	1.1	6.6	8.6	16	7.6	0.8	6.8	9.4	16	0.1 *	0.4	-0.6	0.8	16
Conductivity	umhos/cm	135	52	63	368	16	137	54	69	366	16	2	8	-3	9	16
Diss. Oxygen	mg/L	10.5	2.0	7.7	22.9	16	10.0	1.5	5.4	14.3	16	-0.4	2.8	-12.2	4.2	16
	% sat	102	18	73	203	16	95	15	49	166	16	-2	30	-102	57	16
TS	mg/L	115	45	54	220	10	115	46	70	240	14	8	16	-10	34	10
TVS	mg/L	56	31	28	90	10	49	34	7	140	14	3	22	-12	50	10
TSS	mg/L	2	1	<1	6	16	3	4	<1	9	15	1 *	3	-5	8	15
	lbs/day	69	65	<18	150	16	97	130	16	240	15	32 *	76	-78	220	15
TVSS	mg/L	1	1	<1	2	10	3	2	<1	6	13	1 *	2	<1	6	9
SS	mL/L	<0.1	<0.1	<0.1	<0.1	16	<0.1	<0.1	<0.1	<0.1	16	<0.1	<0.1	<0.1	<0.1	16
NH_3-N	mg/L	<0.01	<0.01	<0.01	0.08	16	0.20	0.36	0.02	0.89	16	0.19 *	0.36	0.01	0.85	16
	lbs/day	0.3	0.5	<0.05	3.2	16	6.9	9.4	0.3	28	16	5.9 *	9.0	0.2	28	16
NO_3-N + NO_2-N	mg/L	1.2	2.0	0.03	3.2	14	1.0	1.7	0.03	2.4	14	0 *	0.19	-1.6	0.02	14
Organic N	mg/L	<0.10	<0.10	<0.10	0.12	16	0.14	0.32	<0.10	1.0	15	0.10 *	0.34	-0.02	0.96	15
	lbs/day	1.9	2.4	0	4.3	16	5.2	10	0	38	15	3.7 *	9.4	-0.7	36	15
Total N	mg/L	1.3	2.0	0.08	3.2	14	0.96	1.8	0.14	3.9	13	0.15	0.58	-1.3	1.6	13
Total P	mg/L	0.02	0.01	<0.01	0.03	16	0.09	0.14	0.02	0.36	16	0.06 *	0.14	0	0.34	16
	lbs/day	0.6	0.6	<0.2	2.4	16	3.8	4.4	0.3	12	16	2.7 *	3.8	0	11	16
COD	mg/L	5	3	<4	10	16	8	3	4	19	16	4 *	4	-2	15	16
	lbs/day	180	240	65	680	16	380	260	130	630	16	120 *	210	-100	400	16
BOD	mg/L	--	--	--	--	--	3	2	<3	5	14	--	--	--	--	--

* Statistically significant ($p<0.05$) difference between influent and effluent, as measured by the Wilcoxon signed-rank test.

Table 4. Correlation matrix of water quality variables affected by Washington fish hatcheries during the summer of 1988. Net change (effluent minus influent) data were used in the correlation analysis. 'LbsCfs', calculated as thousands of pounds on hand divided by flow, was included as an index of fish loading density.

	Temp	pH	TSS	TVSS	NH_3-N	NO_3-N	Org-N	TP	COD	Flow	LbsCfs
Temp	1.00	.	.	.	.	.	.	.	.	.	.
pH	0.54*	1.00	.	.	.	.	.	.	.	.	.
TSS	0.23	0.18	1.00	.	.	.	.	.	.	.	.
TVSS	0.74*	0.51	0.93*	1.00	.	.	.	.	.	.	.
NH_3-N	0.41	0.19	0.91*	0.96*	1.00	.	.	.	.	.	.
NO_3-N	-0.32	-0.82*	-0.39	-0.26	-0.23	1.00	.	.	.	.	.
Org-N	0.63*	0.25	0.72*	0.84*	0.83*	-0.27	1.00	.	.	.	.
TP	0.43	0.25	0.82*	0.77*	0.90*	-0.41	0.82*	1.00	.	.	.
COD	0.19	0.11	0.50	0.82*	0.59*	-0.22	0.51	0.56*	1.00	.	.
Flow	-0.28	-0.45	-0.42	-0.70*	-0.31	0.75*	-0.44	-0.28	-0.49	1.00	.
LbsCfs	0.76*	0.41	0.82*	0.92*	0.91*	-0.35	0.85*	0.87*	0.48	-0.38	1.00

* Statistically significant ($p<0.05$) Spearman rank correlation between variables.

Table 5. Comparison of water quality at state vs. privately-owned fish hatcheries in Washington during the summer of 1988. IQR = Interquartile range; n = sample size. All values represent net change (effluent minus influent), except flow, BOD (effluent only), and loading density (LbsCfs).

		State					Private				
Parameter	Units	Median	IQR	Min.	Max.	n	Median	IQR	Min.	Max.	n
Flow	cfs	9.4	6.0	6.6	14.6	7	5.5 *	4.5	2.0	14.4	9
Temperature	deg C	0.5	1.0	-0.4	1.6	7	2.4 *	1.8	0.0	3.6	9
pH	units	0.1	0.2	-0.1	0.1	7	0.3	0.3	-0.6	0.8	9
Conductivity	umhos/cm	2	4	-2	4	7	6	8	-3	9	9
Diss. Oxygen	mg/L	-0.4	0.6	-1.5	1.3	7	-2.2	3.6	-12.2	4.2	9
	% sat	-1	4	-14	15	7	-18	39	-102	57	9
TS	mg/L	6	14	0	20	4	8	26	-10	34	6
TVS	mg/L	3	34	-9	50	4	2	22	-12	45	6
TSS	mg/L	0	0	0	1	6	2 *	2	-5	8	9
	lbs/day	0	22	0	76	6	59	81	-78	220	9
TVSS	mg/L	0	1	<1	1	3	3	2	<1	6	6
SS	mL/L	<0.1	<0.1	<0.1	<0.1	7	<0.1	<0.1	<0.1	<0.1	9
NH_3-N	mg/L	0.08	0.06	0.02	0.19	7	0.36 *	0.30	0.01	0.85	9
	lbs/day	3.8	1.9	0.7	14	7	11 *	17	0.2	28	9
NO_3-N + NO_2-N	mg/L	0	0	-0.03	0.02	7	-0.19	0.80	-1.6	0.01	7
Organic N	mg/L	<0.10	0.10	-0.02	0.20	6	0.27 *	0.34	<0.10	0.96	9
	lbs/day	<0.6	4.4	-0.7	9.9	6	5.8 *	13	<1.1	36	9
Total N	mg/L	0.07	0.15	-0.03	0.27	6	0.61	1.2	-1.3	1.6	7
Total P	mg/L	0.03	0.03	0.01	0.07	7	0.14 *	0.08	0	0.34	9
	lbs/day	1.9	1.8	0.5	5.5	7	4.1	4.8	0	11	9
COD	mg/L	3	5	-2	6	7	4	3	<4	15	9
	lbs/day	140	310	-100	270	7	110	230	<63	400	9
BOD	mg/L	<3	<3	<3	4	6	4	2	<3	5	8
LbsCfs	lbs x 1000/cfs	1.6	1.1	1.1	3.2	7	9.5 *	18	2.7	29	8

* Statistically significant ($p<0.05$) difference between state and private hatcheries, as measured by the Mann-Whitney test.

Table 6. TWINSPAN analyses of macroinvertebrate collections from three Washington streams receiving fish hatchery effluents during the 1988 summer low flow period. Organism abundance is coded as: R = Rare (1), P = Present (2-4), C = Common (5-25), and A = Abundant (>25). Numerals denote river miles upstream from mouth; "R" denotes replicate sample.

Taxanomic Group	Scatter Creek 8.0	8.0R	8.9	8.9R	7.4	7.4R	6.4R	6.4	3.7	3.7R
Asellidae	C	C	-	-	-	-	-	-	-	-
Physidae	C	-	-	-	P	-	-	-	-	-
Lymnaeidae	P	C	-	-	P	R	-	-	-	-
Leptophlebiidae	-	-	C	C	C	P	-	-	-	-
Perlodidae	-	-	P	C	C	C	R	R	-	-
Oligochaeta	C	C	P	P	P	C	P	P	-	-
Elmidae	-	-	-	-	C	C	-	-	R	R
Nemouridae	-	-	-	-	C	A	C	R	-	-
Baetidae	A	A	A	C	A	A	A	A	A	C
Tipulidae	C	C	-	-	P	C	C	P	P	R
Planorbidae	C	C	-	-	R	R	-	C	-	-
Dytiscidae	P	P	P	-	-	-	P	R	-	-
Hirudinea	A	C	-	-	-	-	C	C	-	-
Simuliidae	C	C	A	C	P	-	A	C	C	C
Chironomidae	C	C	C	C	P	P	A	C	A	C
Limnephilidae	-	-	-	-	R	R	P	-	-	-
Hydracarina	-	-	P	P	-	-	C	-	C	P
Heptageniidae	-	-	-	-	-	-	-	-	P	P
Hydropsychidae	-	-	-	-	-	-	C	C	C	C
Rhyacophilidae	-	-	-	-	-	-	P	P	-	-

Taxanomic Group	Cinebar Creek 1.7R	1.7	1.3R	1.3	1.6R	1.6	1.65	1.65R
Siphlonuridae	-	-	-	-	R	C	-	-
Tipulidae	-	-	P	P	P	R	-	-
Chloroperlidae	C	R	-	C	C	-	-	-
Leuctridae	P	C	-	-	-	-	-	-
Ephemerellidae	C	P	P	P	P	C	-	-
Heptageniidae	A	A	C	C	C	C	-	-
Elmidae	C	C	-	P	C	C	-	-
Hydracarina	C	P	C	P	C	C	C	-
Rhyacophilidae	C	P	R	C	C	C	P	P
Baetidae	C	C	A	A	A	A	A	A
Perlodidae	R	P	P	P	C	A	C	C
Chironomidae	P	P	C	C	A	C	A	A
Oligochaete	-	-	P	P	C	C	C	C
Turbellaria	P	R	P	R	C	C	C	C
Simuliidae	-	-	C	A	C	-	C	P
Nemouridae	-	-	P	P	-	-	-	P
Limnephilidae	-	-	R	R	-	-	R	P
Dytiscidae	-	-	-	-	R	P	C	C
Planorbidae	-	-	-	-	C	P	A	A
Physidae	-	-	-	-	-	-	C	C
Sphaeriidae	-	-	-	-	-	-	C	C

Taxanomic Group	Issaquah Creek 2.6R	2.6	3.1	3.1R	3.0	3.0R
Brachycentridae	P	P	P	R	-	-
Perlidae	P	P	P	P	-	-
Leptophlebiidae	C	C	P	R	-	P
Simuliidae	A	C	R	R	P	R
Perlodidae	A	A	A	C	C	C
Hydracarina	C	A	A	A	A	A
Chloroperlidae	C	P	C	C	C	C
Baetidae	A	A	A	A	A	A
Heptageniidae	C	C	C	C	C	C
Rhyacophilidae	C	C	C	P	C	P
Chironomidae	A	A	C	R	C	C
Elmidae	-	-	R	C	-	P
Nemouridae	R	R	C	P	R	R
Ephemerellidae	P	C	P	P	C	C
Tipulidae	-	-	P	P	C	C
Glossosomatidae	-	-	P	-	R	C
Hirudinea	-	-	-	-	P	P
Oligochaeta	-	-	-	-	P	P

Table 7. Effects of fish hatchery effluents on benthic invertebrate community structure in three Washington streams during the summer of 1988. "R" denotes replicate sample.

Site	River Mile	Taxa Richness Total	Taxa Richness EPT	Similarity of Dominants	Community Loss Coefficient
<u>Scatter Creek</u>					
Pacific Hwy	8.9	8	3	--	--
(Reference site)	8.9R	7	3	--	--
Sea Farm of WA	8.0	11	1	0.30	0.27
effluent plume	8.0R	10	1	0.27	0.30
Leitner Rd	7.4	13	5	0.29	0.15
	7.4R	12	6	0.22	0.17
Domsea Farms	6.4	13	6	0.43	0.15
effluent plume	6.4R	15	6	0.30	0.07
Sargent Rd	3.7	9	3	0.50	0.44
	3.7R	8	3	0.50	0.38
<u>Cinebar Creek</u>					
50m above SR 508	1.7	11	7	--	--
(Reference site)	1.7R	12	8	--	--
Cascade Trout	1.65	13	4	0.07	0.38
effluent plume	1.65R	13	5	0.07	0.54
50m below	1.6	14	6	0.25	0.14
SR 508	1.6R	16	7	0.46	0.12
500m below	1.3	15	8	0.25	0.07
SR 508	1.3R	13	7	0.33	0.31
<u>Issaquah Creek</u>					
Newport Way	3.1	16	11	--	--
(Reference site)	3.1R	15	10	--	--
Footbridge below	3.0	14	8	0.70	0.29
Issaq. Hatchery	3.0R	16	9	0.50	0.12
Dogwood St	2.6	13	10	0.55	0.23
	2.6R	13	10	0.50	0.15

Table 8. Provisional list of chemicals used in aquaculture (adapted from Wood [1979]; Schnick et al. [1986]; Anonymous [1988]; Schnick [1989]; and B. Corey and H. Kocol [FDA, pers. comm.]).

Common Name	Trade Name	Function
<u>Registered or approved for use *</u>		
Acetic acid (vinegar)	--	Parasiticide
Acid blue and acid yellow	Aquashade	Algicide/herbicide
Al + Ca sulfate, boric acid	Clean-Flo Lake Cleanser	Algicide/herbicide
Amitrole	Herbizole	Herbicide
Benzalkonium chloride	Roccal;Hyamine 3500	Disinfectant
Benzethonium chloride	Hyamine 1622	Bactericide
Calcium hypochlorite	--	Disinfectant
Carbaryl	Sevin	Insecticide
Carbonic acid	--	Anesthetic
Chlorine	--	Disinfectant
Copper elemental	(many)	Algicide/herbicide
Copper sulfate	(many)	Algicide/herbicide
Dichlobenil	Casoron-10G	Herbicide
Dichlone	Dichlone 50 WP	Algicide
Didecyl dimethyl ammonium chloride	Sanaqua	Disinfectant
Diquat dibromide	(many)	Herbicide/bactericide
Endothall	(many)	Algicide/herbicide
Erythromycin	Gallimycin-50	Bactericide
Fluorescein sodium	--	Water dye
Fluridone	Sonar	Herbicide
Formalin	Formalin-F	Parasiticide/fungicide
Glyphosate	Rodeo	Herbicide
Iodophors	Wescodyne;Betadine	Egg disinfectant
Lime	--	Pond sterilant
Malachite green	--	Fungicide
Nifurpirinol	Furanace-10	Bactericide
Oxytetracycline	Terramycin;TM-50	Bactericide;fish dye
Potassium permanganate	--	Oxidant/antimicrobial
Potassium ricinoleate	Solricin 135	Algicide
Rhodamine B and WT	--	Water dye
Sodium chloride (salt)	--	Osmoregulatory enhancer
Simazine	Aquazine	Algicide/herbicide
Sodium bicarbonate	--	Anesthetic
Sulfadimethoxine + ormetoprim	Romet-30;Romet-B	Bactericide
Sulfamerazine	--	Bactericide
Sulfamethazine	Sulmet	Bactericide
Tetracycline	--	Dye to mark fish
Tricaine methane-sulfonate	Finquel;MS-222	Anesthetic
Trichlorfon	Masoten	Parasiticide
Xylene	--	Herbicide
2,4-D	(many)	Herbicide

Table 8. Continued

Common Name	Trade Name	Function
Not approved for use		
Astaxanthin	--	Flesh coloration
Canthaxanthin	--	Flesh coloration
Chloral hydrate	--	Anesthetic
Chloramine-T	--	Disinfectant/bactericide
Chloramphenicol	--	Antimicrobial
Ciclohexamide	--	Antimicrobial
Diameton	--	Bactericide
Diflubenzuron	Dimilin	Parasiticide
Ethyl aminobenzoate	Benzocaine	Anesthetic
Fenbendazole	--	Parasiticide
Flumequine	--	Bactericide
Furazolidone	Furox-50	Bactericide
Gentamycin	--	Bactericide
Kanamycin Sulfate	--	Bactericide
Mercurous chloride	Calomel	Protozoacide
Methylene blue	--	Protozoacide/fungicide
Metomidate	--	Anesthetic
Metronidazole	--	Protozoacide
Nalidixic acid	--	Bactericide
Neomycin	--	Bactericide
Niclosamide	Yomesan	Parasiticide
Nitrofurazone	Furacin	Bactericide
Oxolinic acid	--	Bactericide
Penicillin	--	Bactericide
Polycillin	--	Bactericide
Praziquantel	Droncit	Parasiticide
Pyridylmercuric acetate	--	Bactericide
Quinacrine hydrochloride	--	Antimicrobial
Sodium sulfathiazole	--	Antimicrobial
Streptomycin	--	Bactericide
Streptomycin + penicillin	Combiotic	Bactericide
Sulfisoxazole	--	Bactericide
Terbutryn	I Gran	Herbicide
Testosterone	--	Sex reversal
Trifluralin	--	Fungicide
Virginiamycin	--	Bactericide

* Uses are often severely restricted (e.g., some of these compounds have only been approved for use at a few locations; also, individual states may prohibit the use of certain chemicals). Two additional classes of compounds are approved but not included here: 1) aquatic pesticides used for mosquito control (subject to certain requirements); and 2) fish toxicants (piscicides).

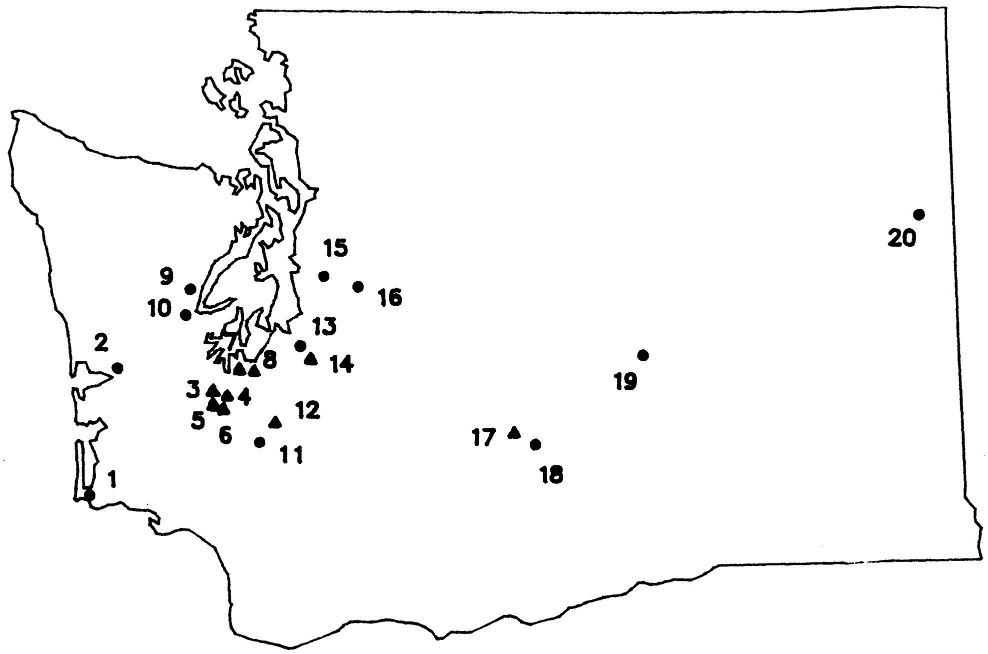
Table 9. Recommended effluent limitations and monitoring requirements for freshwater fish hatcheries in Washington. General discharge limits must be met by all hatcheries, including those with off-line cleaning waste treatment.

	Effluent Limitation		Monitoring Requirement	
Parameter	Monthly Average	Instantaneous Maximum	Minimum Frequency	Type of Sample*
General Hatchery Discharge				
Flow (mgd)	--	--	2/month	Daily total
Temp. (deg C)	--	--	2/month**	U&D grabs
Oxygen (mg/L)	--	--	2/month**	U&D grab
SS (net mL/L)	0.1	--	2/week	I&E grabs
TSS (net mg/L)	5.0	--	2/month	I&E composites
TSS (net mg/L)	--	15	--	I&E grabs
Cleaning Waste Treatment System				
Flow (mgd)	--	--	1/week	Daily total
SS (mL/L)	--	1.0	1/week	E grab
SS (% removal)	90	--	1/week	I&E grabs
TSS (mg/L)	--	100	1/month	E grab
TSS (% removal)	85	--	1/month	I&E grabs
Rearing Pond Drawdown				
SS (mL/L)	--	1.0	1/drawdown	E grab
TSS (mg/L)	--	100	1/drawdown	E grab

* - U=Receiving water upstream of hatchery intake or influence; D=Receiving water at downstream boundary of authorized dilution zone; I=Hatchery influent; E=Hatchery effluent.
- Composite samples shall be a combination of 4 grabs taken over 8 hours.
- If a facility has multiple outfalls, sample volumes should be weighted in proportion to flow.
- Monitoring for cleaning waste treatment and drawdown compliance should occur during the last quarter of the cleaning or drawdown event.

** - June through September only; measurement should be taken in the afternoon.

FIGURES



1 Naselle (WDF)
2 Aberdeen (WDW)
3 Domsea Farms Inc.
4 Sea Farm of WA Inc.
5 Swecker Salmon Farm Inc.
6 Steelhammer Salmon Farm Inc.
7 Nisqually Trout Farm #2
8 Nisqually Trout Farm #1
9 Hood Canal (WDF)
10 George Adams (WDF)
11 Cowlitz (WDF)
12 Cascade Trout Farm
13 Puyallup (WDW)
14 Trout Springs (Troutlodge Inc.)
15 Issaquah (WDF)
16 Tokul Creek (WDW)
17 Trout Meadows Ranch
18 Yakima (WDW)
19 Columbia Basin (WDW)
20 Spokane (WDW)

Figure 1. Location of Washington fish hatcheries sampled during the 1988 summer low flow season. Triangles denote privately owned hatcheries; circles denote state-owned facilities.

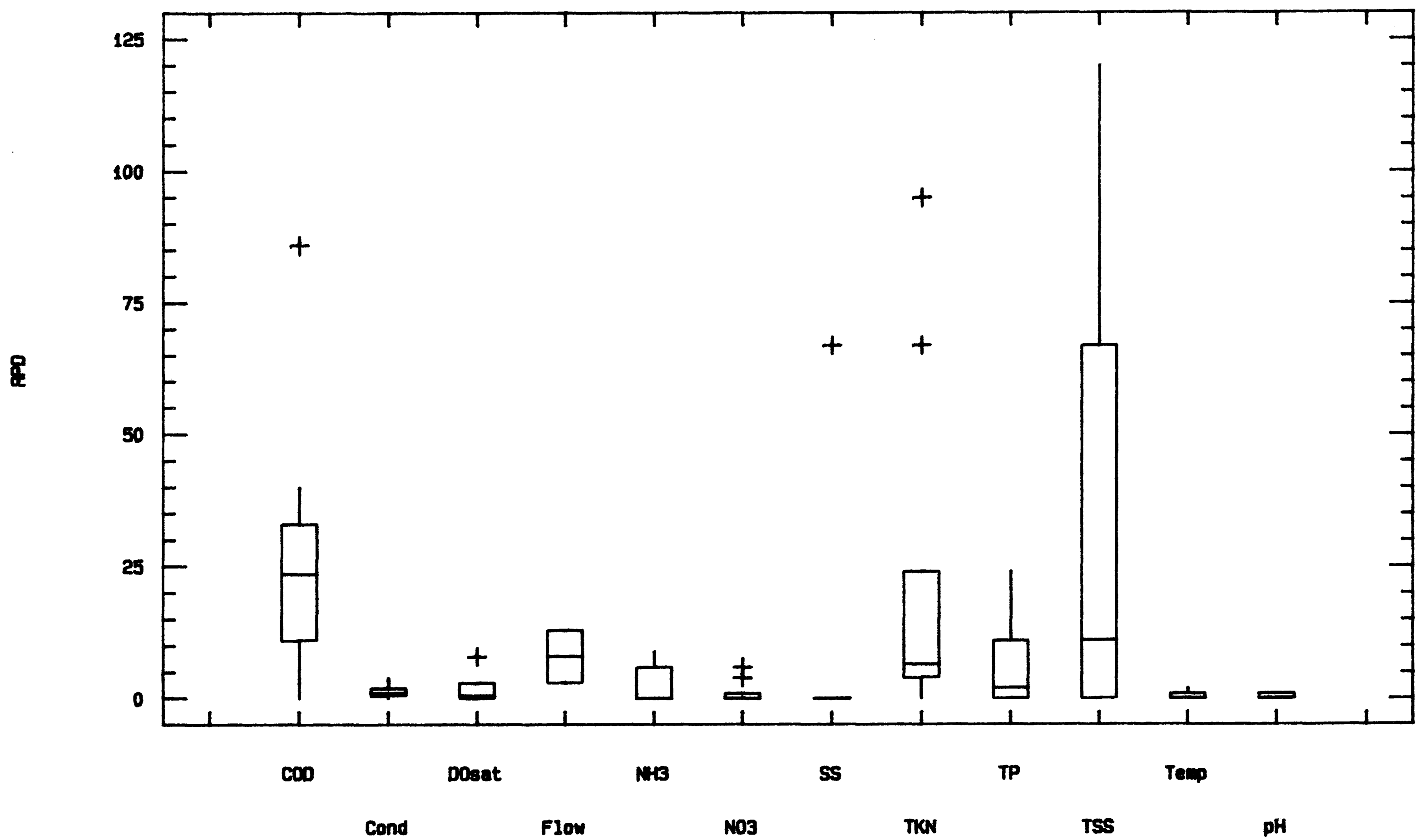


Figure 2. Comparison of replicate samples and measurements from the Washington fish hatchery effluent study (June-September 1988). Parameter abbreviations are keyed inTable 2.

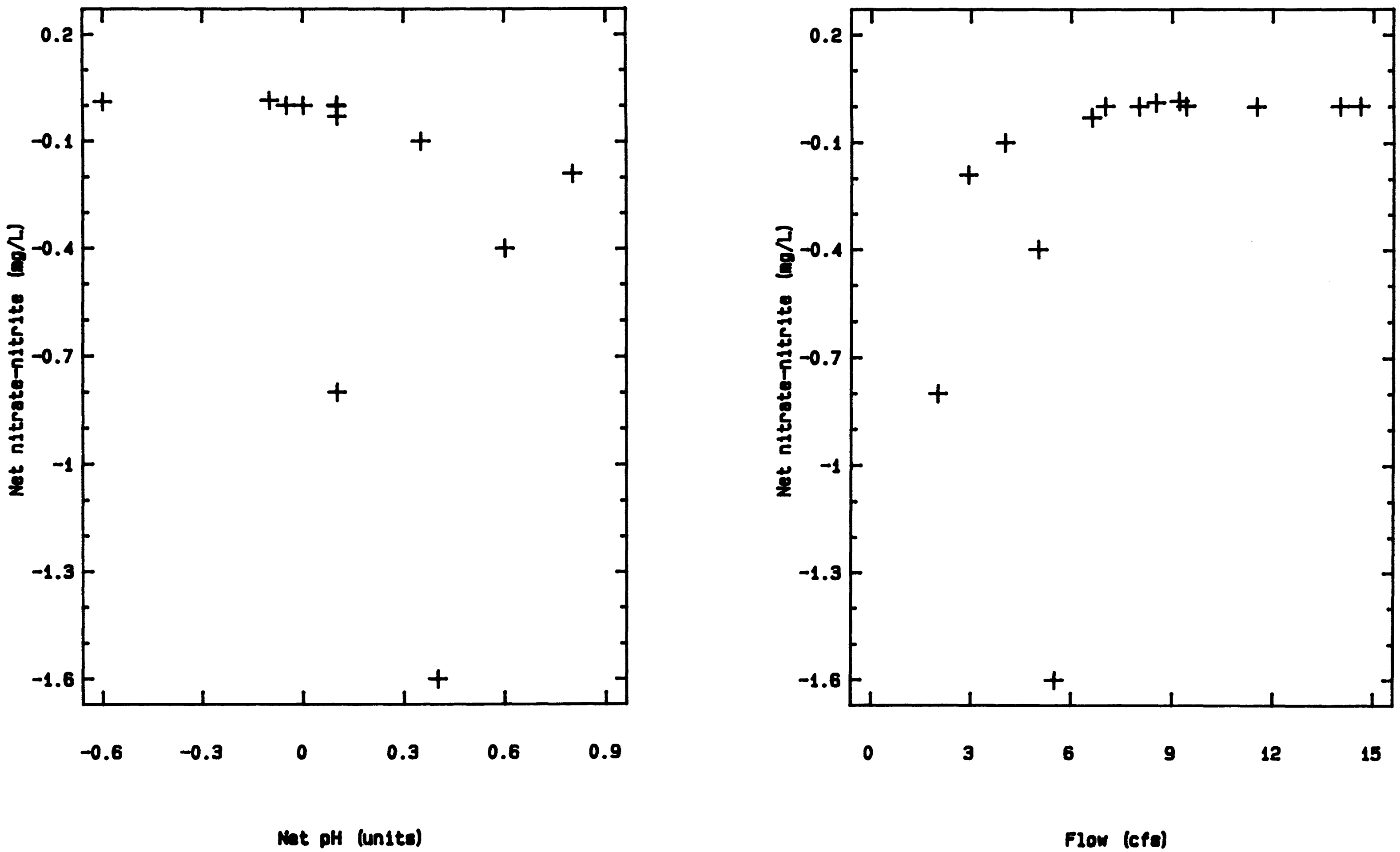


Figure 3. Relationship between net changes in pH and nitrate-nitrite (rank $r = -0.82$, $p < 0.01$) and between flow and net nitrate-nitrite (rank $r = 0.75$, $p < 0.01$) at several Washington fish hatcheries.

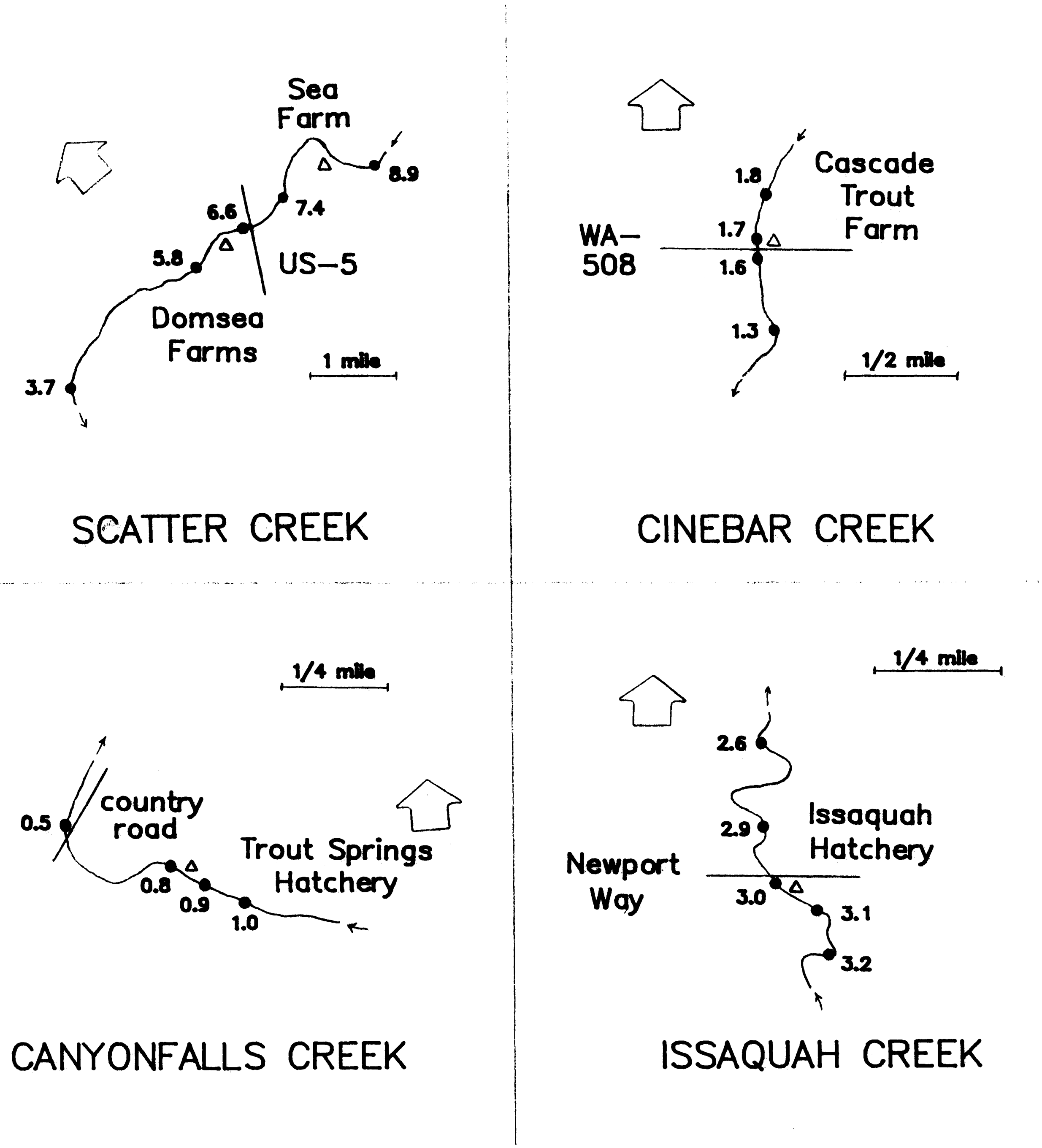


Figure 4. Map of four Washington streams receiving fish hatchery effluent during the 1988 summer low flow period. Darkened circles denote sampling sites; numerals denote river mile identifiers; triangles denote fish hatcheries.

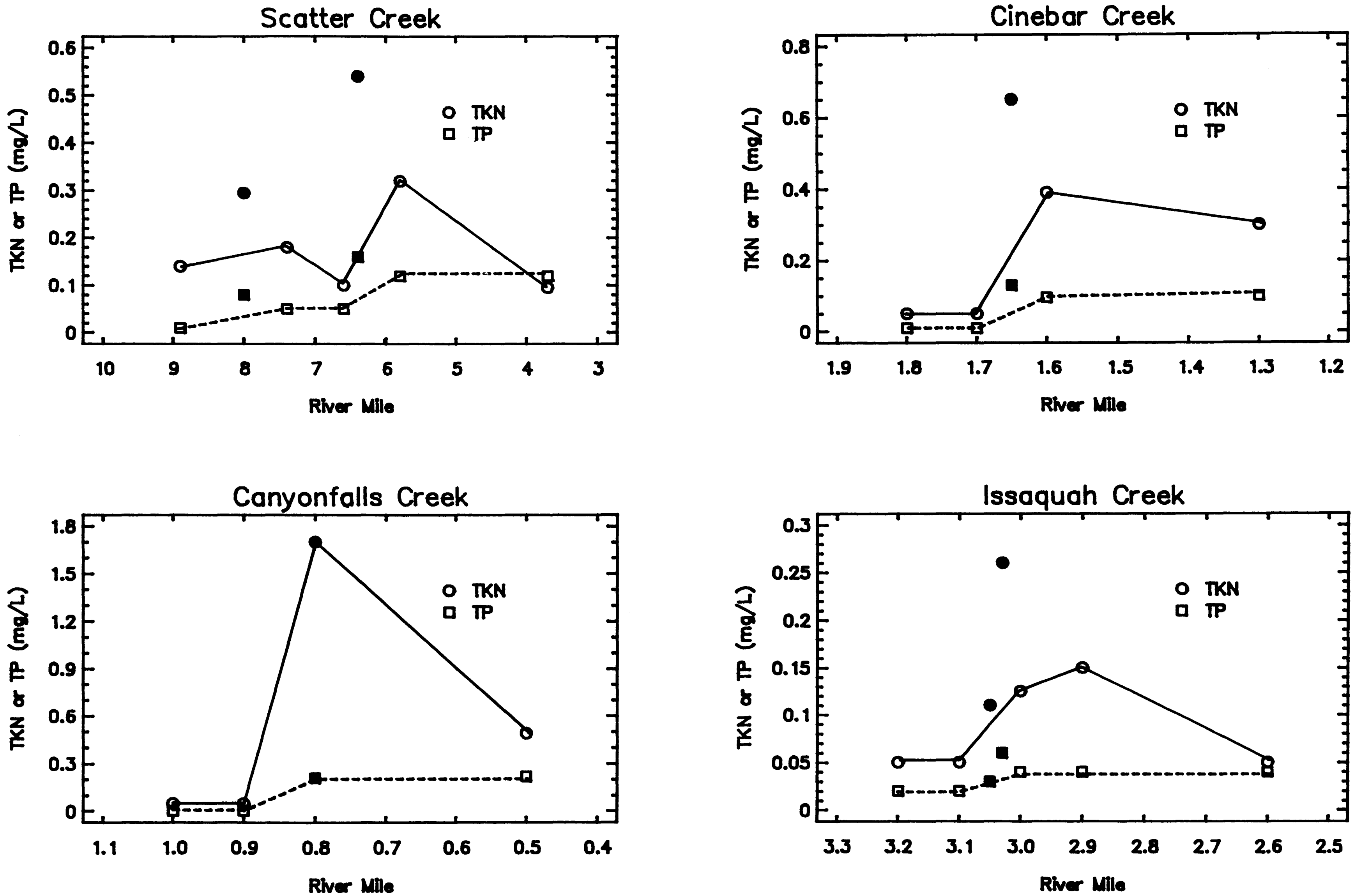
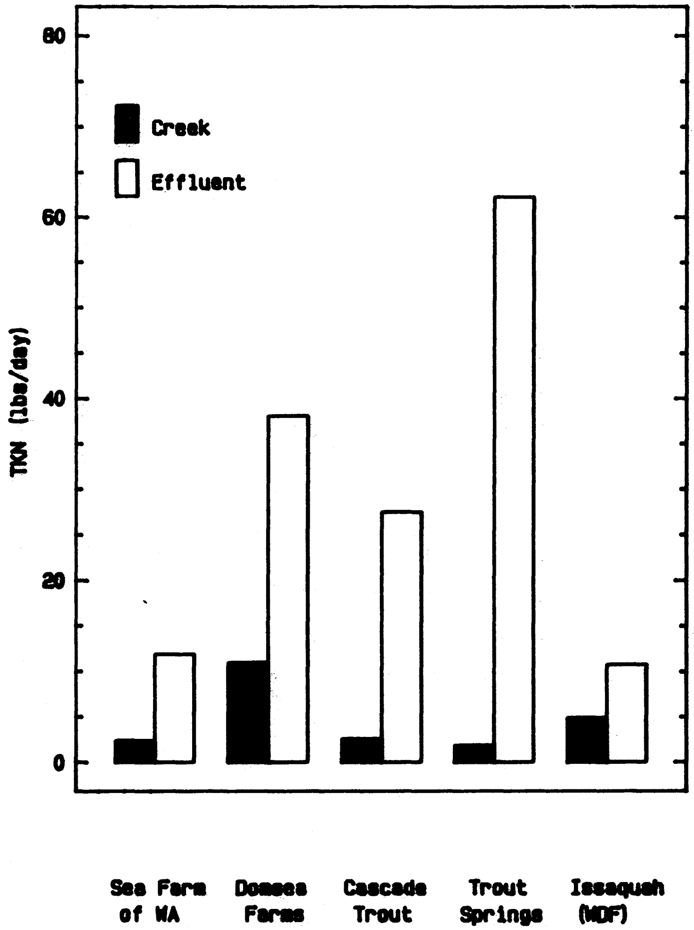


Figure 5. Effect of fish hatchery effluents on instream nutrient concentrations at four Washington creeks surveyed during the 1988 summer low flow period. Darkened symbols denote hatchery effluents; lines connect receiving water stations.



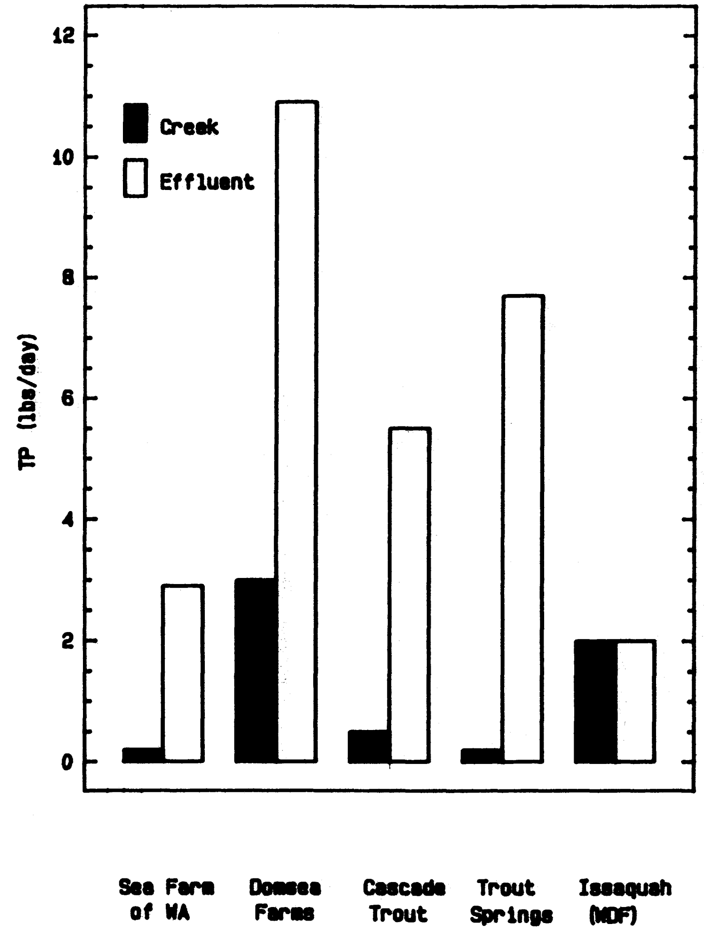


Figure 6. Comparison of nutrient loads carried by five fish hatcheries and receiving environments (upstream of discharge) in Washington during the 1988 summer low flow period.

APPENDICES

Appendix A. Wastewater quality at 20 Washington fish hatcheries sampled in the summer of 1988.

Site	Sample Type*	Date	Time	Flow** (cfs)	Temp. (deg C)	pH (units)	Cond.*** (umhos/cm)	Diss. Oxygen (mg/L)	Diss. Oxygen (% sat)	Solids*** TS (mg/L)	Solids*** TNVS (mg/L)	Solids*** TSS (mg/L)	Solids*** TNVSS (mg/L)	Solids*** SS (mL/L)	Nutrients*** NH_3-N (mg/L)	Nutrients*** NO_3-N + NO_2-N (mg/L)	Nutrients*** TKN (mg/L)	Nutrients*** Total P (mg/L)	Oxygen Demand*** COD (mg/L)	Oxygen Demand*** BOD-5 (mg/L)
Naselle Salmon Hatchery (WDF)	IG	6/1	1330	--	9.9	7.5	58	--	--	85	45	5	<1	<0.1	<0.01	0.33	<0.10	0.01	5	--
	EG-P	6/1	1305	17JF	10.4	7.6	62	9.85	88	78	53	7	4	<0.1	0.14	0.34	0.30	0.03	6	<3
	EG-P-RE	6/1	1345	>17JF	10.7	6.7	62	7.00	63	110	74	30	22	0.3	0.11	0.33	0.52	0.30	18	3
	EG-P-RE	6/1	1430	--	10.8	7.1	60	12.10	109	180	130	94	69	1.1	0.12	0.34	1.3	0.11	56	--
Sea Farm of Washington, Inc.	IG	7/12	0940	--	10.3	7.0	150	11.35	102	--	--	1	--	<0.1	<0.01	2.6J	<0.10	0.02	<4	--
	IG	7/12	1540	--	10.4	6.7	150	11.35	102	--	--	2	--	<0.1	<0.01	2.6J	<0.10	0.02	5	--
	MG	7/12	1600	--	10.8	6.9	435	9.55	87	--	--	1	--	<0.1	0.14	2.5J	<0.10I	0.06	22I	--
	MG	7/13	1045	9J	10.3	7.0	150	9.70	87	--	--	4	--	<0.1	0.08	2.5J	0.10	0.13	<4	--
	MG	7/13	1350	--	10.5	6.9	260	9.65	87	--	--	2	--	<0.1	0.12	2.5J	<0.10I	0.05	9I	--
	EG	7/12	0915	--	10.3	6.8	150	9.20	82	--	--	<1	--	<0.1	0.16	2.5J	0.34	0.08	5	--
	EG	7/12	1615	--	10.6	6.8	710	9.10	82	--	--	<1	--	<0.1	0.19	2.5J	<0.10I	0.09	18I	--
	EG	7/13	1035	--	10.7	6.7	153	9.15	83	--	--	2	--	<0.1	0.13	2.4J	0.25	0.08	5	--
	EG	7/13	1340	--	10.6	6.9	530	9.25	84	--	--	2	--	<0.1	0.17	2.6J	<0.10I	0.07	9I	<3
	EG-R	7/13	1340	--	10.6	6.8	510	9.30	84	--	--	2	--	<0.1	0.18	2.5J	<0.10I	0.07	8I	--
	EC	7/13	0900	--	--	--	159	--	--	140	110	4	1	<0.1	0.20	2.5J	<0.10I	0.08	6I	<3
Domsea Farms, Inc.	IG	7/12	1140	--	10.1	6.6	120	22.75	203	--	--	<1	--	<0.1	<0.01	1.9J	<0.10	0.02	5	--
	IG	7/12	1640	--	9.8	6.6	126	23.00	203	--	--	1	--	<0.1	<0.01	1.9J	<0.10	0.02	<4	--
	MG	7/12	1700	--	10.8	6.8	138	10.35	94	--	--	2	--	<0.1	0.50	2.1J	0.93	0.20	8	--
	MG	7/13	0820	--	10.2	6.9	130	10.40	93	--	--	2	--	<0.1	0.34	1.9J	0.47	0.18	6	--
	MG	7/13	1320	--	11.0	6.7	136	10.75	98	--	--	2	--	<0.1	0.36	1.9J	0.68	0.20	8	--
	EG	7/12	1130	--	12.7	7.0	130	10.40	98	--	--	2	--	<0.1	0.36	2.3J	0.72	0.15	6	--
	EG	7/12	1715	--	12.9	6.9	130	11.60	110	--	--	1	--	<0.1	0.34	1.8J	0.72	0.15	5	--
	EG	7/13	0805	14.4	12.2	6.9	130	8.90	83	--	--	2	--	<0.1	0.41	1.9J	0.54	0.16	9	--
	EG	7/13	1300	--	12.9	6.9	130	10.85	103	--	--	1	--	<0.1	0.39	1.8J	0.58	0.15	10	<3
	EG-R	7/13	1300	--	12.7	6.8	130	10.90	103	--	--	2	--	<0.1	0.39	1.8J	0.56	0.16	8	--
	EC	7/13	1200	--	--	--	132	--	--	94	87	1	1	<0.1	0.36	1.7J	0.54	0.16	29A	15A
Cascade Trout Farm	IG	7/19	1630	--	15.8	7.4	65	10.00	104	--	--	2	--	<0.1	0.03	0.04	<0.10	0.01	7	--
	IG	7/20	0930	--	12.7	7.6	64	10.55	102	--	--	2	--	<0.1	<0.01	0.03	<0.10	0.01	4	--
	IG	7/20	1205	--	14.2	7.6	64	10.40	104	--	--	2	--	<0.1	0.01	0.03	<0.10	0.01	6	--
	IC	7/20	0945	--	--	--	63	--	--	54	20	3	1	<0.1	<0.01	0.04	<0.10	0.01	8	--
	EG	7/19	1645	--	16.9	6.9	67	8.10	86	--	--	5	--	<0.1	0.22	0.05	0.50	0.12	12	--
	EG	7/20	0845	8.5	14.3	7.0	67	8.00	80	--	--	3	--	<0.1	0.23	0.04	0.62	0.12	9	--
	EG	7/20	1220	--	15.6	7.1	68	8.25	85	--	--	4	--	<0.1	0.18	0.05	0.50	0.11	9	<3
	EG-R	7/20	1220	--	15.7	7.1	67	8.30	86	--	--	4	--	<0.1	0.18	0.05	0.54	0.11	9	--
	EC	7/20	1000	--	--	--	69	--	--	70	22	4	1	<0.1	0.24	0.05	0.65	0.13	11	3
Puyallup Trout Hatchery (WDW)	IG	7/26	1620	--	10.2	7.3	185	10.60	94	130	60	2	<1	<0.1	<0.01	1.8	<0.10	0.01	10	--
	EG	7/26	1555	9.4	11.8	7.4	183	10.20	94	140	63	2	<1	<0.1	0.08	1.8	0.32	0.06	8	<3
	EG-CE	7/27	0930	--	10.1	7.4	173	9.95	88	--	--	3	--	<0.1	0.06	1.8	<0.10	0.13	6	3
	EG-CE-R	7/27	0930	--	10.1	7.4	174	9.70	86	--	--	3	--	<0.1	0.06	1.8	<0.10	0.11	8	--
Trout Springs (Troutlodge, Inc.)	IG	7/26	1315	--	11.2	7.4	180	10.30	95	--	--	<1	--	<0.1	<0.01	1.7	<0.10	<0.01	<4	--
	IG	7/27	1040	--	10.2	7.5	181	10.10	91	140	70	1	<1	<0.1	<0.01	1.7	<0.10	<0.01	4	--
	IG	7/27	1500	--	10.5	7.7	180	10.20	92	--	--	1	--	<0.1	<0.01	1.8	<0.10	<0.01	<4	--
	EG	7/26	1350	--	13.8	7.7	234A	11.20	109	--	--	4	--	<0.1	0.52	1.8	1.6	0.19	10	--
	EG	7/27	1100	--	11.7	7.6	190	9.80	91	--	--	2	--	<0.1	0.71	1.8	1.6	0.22	14	5
	EG-R	7/27	1100	--	11.5	7.6	191	10.10	94	--	--	3	--	<0.1	0.70	1.8	1.6	0.23	10	--
	EG	7/27	1520	7J	14.5	7.6	191	10.60	105	--	--	3	--	<0.1	0.81	1.8	1.8	0.23	12	--
	EC	7/27	1120	--	--	--	188	--	--	130	72	4	<1	<0.1	0.69	1.7	1.7	0.21	10	4
Spokane Trout Hatchery (WDW)	IG	8/2	1450	14J	10.6	7.6	368	7.70	73	220	130	2	1	<0.1	0.01	2.2	<0.10	0.01	9	--
	EG-RP	8/2	1500	--	11.7	7.7	366	9.00	88	240	100	3	1	<0.1	0.20	2.2	0.13I	0.04	8	<3
George Adams Salmon Hatchery (WDF)	IG	8/2	0920	--	9.6	7.7	79	12.00	105	86	13	1	<1	<0.1	<0.01	0.03	<0.10	0.03	5	--
	EG	8/2	0940	14.6	10.1	7.7	83	11.50	102	89	25	1	1	<0.1	0.04	0.03	0.11	0.10	8	<3

Appendix A. Continued

								Diss. Oxygen		Solids***					Nutrients***				Oxygen Demand***	
Site	Sample Type*	Date	Time	Flow** (cfs)	Temp. (deg C)	pH (units)	Cond.*** (umhos/cm)	(mg/L)	(% sat)	TS (mg/L)	TNVS (mg/L)	TSS (mg/L)	TNVSS (mg/L)	SS (mL/L)	NH_3-N (mg/L)	NO_3-N + NO_2-N (mg/L)	TKN (mg/L)	Total P (mg/L)	COD (mg/L)	BOD-5 (mg/L)
Steelhammer	IG	8/2	1230	4J	10.4	6.8	119	8.90	80	95	36	1	1	<0.1	0.05	2.2	<0.10	0.03	7	--
Salmon Farm,	EG-RP1	8/2	1205	--	11.9	7.1	126	9.70	90	100	51	5	1	<0.1	0.72	2.3	1.0	0.26	14	4
Inc.	EG-RP2	8/2	1220	--	11.9	7.2	128	9.65	89	100	42	4	2	<0.1	0.41	1.9	0.67	0.18	10	--
Swecker Salmon	IG	8/2	1400	--	10.9	6.9	150	8.75	79	96	57	1	1	<0.1	0.04	2.8	<0.10	0.02	4	--
Farm, Inc.	EG-RP	8/2	1435	5J	14.4	7.5	148	9.80	96	130	46	9	3	<0.1	0.89	2.4	1.5	0.36	19	5
Cowlitz Salmon	IG	8/16	1025	--	11.2	7.5	60	11.75	108	67	35	4	1	<0.1	<0.01	0.03	<0.10	0.01	8	--
Hatchery (WDF)	EG-CE	8/16	1110	150J	11.4	7.2	65	11.40	105	53	30	5	<1	<0.1	0.05	0.03	0.13	0.04	8	3
Nisqually	IG	8/17	1100	--	10.4	8.0	200	11.60	104	140	100	2	<1	<0.1	<0.01	2.1	<0.10	0.02	6	--
Trout Farm #1	EG	8/17	1125	2J	12.8	8.1	200	5.90	56	150	100	5	1	<0.1	0.52	1.3	1.0	0.23	12	4
Nisqually	IG	8/17	0930	--	11.4	6.8	150	8.25	75	130	78	3	<1	<0.1	0.01	3.2	<0.10	0.02	6	--
Trout Farm #2	EG	8/17	1015	5.5	11.4	7.2	147	5.40	49	120	76	5	2	<0.1	0.22	1.6	0.36	0.15	9	4
Hood Canal	IG	8/17	1355	11.5	9.5	7.8	92	11.60	101	100	72	2	<1	<0.1	<0.01	0.06	<0.10	0.03	5	--
Salmon	EG	8/17	1415	--	10.4	7.9	94	11.20	100	100	73	12A	7A	<0.1	0.08	0.06	<0.10	0.06	4	<3
Hatchery (WDF)																				
Yakima Trout	IG	8/23	0830	--	14.8	7.7	188	10.55	108	170	140	<1	<1	<0.1	0.01	0.87	<0.10	0.10	<4	--
Hatchery (WDW)	EG-P	8/23	0850	0.4F	15.2	7.4	193	4.40	45	180	150	1	1	<0.1	0.23	0.87	0.43	0.22	6	3
	EG-P-CE	8/23	0900	>0.4F	15.2	7.6	192	6.75	69	250	170	88	19	2.5	0.14	0.86	1.7	4.0	130	32
Trout Meadows	IG	8/23	1415	2.9	17.3	8.6	106	10.10	109	--	--	6	--	<0.1	0.01	0.24	<0.10	0.02	6	--
Ranch	EG	8/23	1515	--	20.9	9.4	107	14.30	166	--	--	1	--	<0.1	0.02	0.05	0.13	0.02	8	--
Columbia Basin	IG	8/24	1115	--	15.6	7.8	485	10.15	106	--	--	<1	--	<0.1	<0.01	2.1	<0.10	0.05	<4	--
Trout Hatchery	EG-CE	8/24	1030	18.5	15.8	7.9	480	8.55	89	--	--	1	--	<0.1	0.11	2.0	0.19	0.14	8	--
(WDW)	EG-CE-R	8/24	1030	--	15.8	7.9	482	9.15	96	--	--	4	--	0.1	0.12	2.0	0.23	0.11	8	--
Tokul Creek	IG	8/24	1610	--	15.1	8.0	125	10.40	103	--	--	<1	--	<0.1	0.01	0.36	0.13	0.01	<4	--
Trout Hatchery	EG-P	8/24	1625	6.6F	15.2	8.1	127	10.50	104	--	--	<1	--	<0.1	0.03	0.33	0.13	0.03	6	--
(WDW)																				
Aberdeen Trout	IG	8/30	1010	--	18.3	--	66	9.65	102	72	42	2	<1	<0.1	<0.01	0.02	<0.10	0.01	<4	--
Hatchery (WDW)	EG-P1	8/30	1100	6JF	18.4	--	67	8.35	88	68	44	1	<1	<0.1	0.11	0.02	0.20	0.03	6	4
	EG-P2-CE	8/30	1045	--	18.8	--	75	7.70	82	89	42	12	4	0.1	0.27	0.02	0.82	0.56	21	12
Issaquah Salmon	IG	9/6	1730	--	14.3	8.0	128	10.45	102	--	--	1	--	<0.1	0.02	0.71	<0.10	0.02	5	--
Hatchery (WDF)	IG	9/7	1345	--	14.8	8.2	128	10.85	107	--	--	1	--	<0.1	0.01	0.70	<0.10	0.02	<4	--
Raceways	EG	9/6	1630	--	14.3	8.0	126	10.50	102	--	--	<1	--	<0.1	0.10	0.72	<0.10	0.04	<4	--
	EG	9/7	1315	9.2	14.0	8.0	129	10.55	102	--	--	2	--	<0.1	0.10	0.72	<0.10	0.04	4	--
	EC	9/7	0950	--	--	--	130	--	--	92	62	1	1	<0.1	0.09	0.72	0.11	0.03	9	3
Issaquah Salmon	IG	9/6	1710	--	14.6	8.0	142	10.60	104	--	--	1	--	<0.1	0.10	0.70	0.11	0.03	5	--
Hatchery (WDF)	IG	9/7	1150	--	13.9	8.0	142	10.90	105	--	--	2	--	<0.1	0.05	0.70	<0.10	0.02	5	--
Rearing Ponds	EG-RP1	9/6	1655	--	15.0	8.0	142	9.45	93	--	--	1	--	<0.1	0.19	0.70	0.32	0.06	6	--
	EG-RP1	9/7	1100	8JF	13.9	7.9	149	9.05	87	--	--	2	--	<0.1	0.17	0.70	0.28	0.05	4	--
	EG-RP1-R	9/7	1100	--	13.8	7.9	146	9.05	87	--	--	2	--	<0.1	0.16	0.71	0.27	0.05	6	--
	EG-P2	9/7	1130	2JF	14.1	8.0	143	10.95	106	--	--	1	--	<0.1	0.04	0.70	<0.10	0.03	5	--
	EC-RP1	9/7	1015	--	--	--	142	--	--	110	98	2	1	<0.1	0.17	0.70	0.26	0.06	9	4

* IG = Influent grab; EG = Effluent grab; P = Sample not representative of whole effluent (e.g., may be one of several outfalls); RE = Release event; MG = Effluent grab upstream of settling pond; R = Replicate sample; EC = Effluent composite; IC = Influent composite; CE = Cleaning event; Numerals discriminate multiple outfalls; RP = Sample does not include entire effluent, but is considered representative of bulk of outflow.

** Unless otherwise noted, reported values represent flow rates for entire facility; J = Estimate value - not accurate; F = Flow of specific waste stream sampled.

*** J = Estimated value - not accurate; I = Analytical interference due to inorganic salts or solids - datum considered invalid; A = Unexplainable aberrant value -- datum considered invalid.

Appendix B. Water quality in four Washington streams receiving fish hatchery effluent during the summer of 1988.

Site	River Mile	Date	Time	Flow (cfs)	Temp. (deg C)	pH (units)	Cond. (umhos/cm)	Diss. Oxygen (mg/L)	Diss. Oxygen (% sat)	Solids TSS (mg/L)	Solids SS (mL/L)	Nutrients NH_3-N (mg/L)	Nutrients NO_3-N + NO_2-N (mg/L)	Nutrients TKN (mg/L)	Nutrients Total P (mg/L)	COD (mg/L)	BOD-5 (mg/L)
Scatter Creek																	
Pacific Hwy	8.9	7/13	1020	3.2	14.1	7.0	96	9.40	92	2	<0.1	<0.01	0.21J	0.14	0.01	7	--
Sea Farm of WA	8.0	7/13	1035	9J	10.7	6.7	153	9.15	83	2	<0.1	0.13	2.4J	0.25	0.08	5	--
Inc. effluent			1340	--	10.6	6.9	530	9.25	84	2	<0.1	0.17	2.6J	<0.10I	0.07	9I	<3
			1340R	--	10.6	6.8	510	9.30	84	2	<0.1	0.18	2.5J	0.10I	0.07	8I	--
Leitner Rd	7.4	7/13	1435	11.3	12.8	7.3	140	11.00	104	1	<0.1	<0.01	1.9J	0.18	0.05	4	--
Case Rd	6.6	7/13	1450	--	13.2	7.4	166	11.30	108	4	<0.1	0.02	1.9J	0.10	0.05	8	--
Domsea Farms	6.4	7/13	0805	14.4	12.2	6.9	130	8.90	83	2	<0.1	0.41	1.9J	0.54	0.16	9	--
Inc. effluent			1300	--	12.9	6.9	130	10.85	103	1	<0.1	0.39	1.8J	0.58	0.15	10	<3
			1300R	--	12.7	6.8	130	10.90	103	2	<0.1	0.39	1.8J	0.56	0.16	8	--
Guava St	5.8	7/13	1515	--	13.4	7.1	180	10.75	103	2	<0.1	0.24	2.0J	0.32	0.12	9	--
Sargent Rd	3.7	7/13	1620	21.9	15.0	7.6	154	11.25	112	5	<0.1	<0.01	1.7J	0.14	0.12	9	--
			1620R	21.2	15.0	7.7	152	11.25	112	4	<0.1	<0.01	1.8J	<0.10	0.12	10	--
Cinebar Creek																	
Cascade Trout	1.8	7/20	0930	--	12.7	7.6	64	10.55	102	2	<0.1	<0.01	0.03	<0.10	0.01	4	--
Farm inlet			1205	--	14.2	7.6	64	10.40	104	2	<0.1	0.01	0.03	<0.10	0.01	6	--
50m above SR 508	1.7	7/20	1410	1.1	16.0	7.5	63	9.80	102	2	<0.1	<0.01	0.03	<0.10	0.01	7	--
Cascade Trout	1.65	7/20	0845	8.5	14.3	7.0	67	8.00	80	3	<0.1	0.23	0.04	0.62	0.12	9	--
Farm effluent			1220	--	15.6	7.1	68	8.25	85	4	<0.1	0.18	0.05	0.50	0.11	9	<3
			1220R	--	15.7	7.1	67	8.30	86	4	<0.1	0.18	0.05	0.54	0.11	9	--
50m below SR 508	1.6	7/20	1300	7.9	15.9	7.2	65	8.95	93	5	<0.1	0.15	0.05	0.38	0.09	7	--
			1300R	9.0	15.9	7.2	64	8.70	90	5	<0.1	0.15	0.05	0.40	0.10	9	--
500m below SR 508	1.3	7/20	1100	8.2	15.5	7.3	66	9.50	98	5	<0.1	0.10	0.15	0.30	0.10	7	--

Appendix B. Continued

Site	River Mile	Date	Time	Flow (cfs)	Temp. (deg C)	pH (units)	Cond. (umhos/cm)	Diss. Oxygen (mg/L)	Diss. Oxygen (% sat)	Solids TSS (mg/L)	Solids SS (mL/L)	Nutrients NH_3-N (mg/L)	Nutrients NO_3-N + NO_2-N (mg/L)	Nutrients TKN (mg/L)	Nutrients Total P (mg/L)	COD (mg/L)	BOD-5 (mg/L)
Canyonfalls Creek																	
Logging road	1.0	7/27	1440	--	11.2	7.6	187	10.20	94	1	<0.1	0.06	1.8	<0.10	<0.01	<4	--
Trout Springs Inc.																	
Inlet	0.9	7/27	1040	--	10.2	7.5	181	10.10	91	1	<0.1	<0.01	1.7	<0.10	<0.01	4	--
			1500	--	10.5	7.7	180	10.20	92	1	<0.1	<0.01	1.8	<0.10	<0.01	<4	--
Outlet	0.8	7/27	1100	--	11.7	7.6	190	9.80	91	2	<0.1	0.71	1.8	1.6	0.22	14	5
			1100R	--	11.5	7.6	191	10.10	94	3	<0.1	0.70	1.8	1.6	0.23	10	--
			1520	--	14.5	7.6	191	10.60	105	3	<0.1	0.81	1.8	1.8	0.23	12	--
Country road	0.5	7/27	1340	7.4	13.0	7.9	188	10.00	95	3	<0.1	0.20	2.4	0.49	0.22	9	--
Issaquah Creek																	
Issaquah Hatchery raceway inlet	3.2	9/7	1345	--	14.8	8.2	128	10.85	107	1	<0.1	0.01	0.70	<0.10	0.02	<4	--
Newport Way	3.1C	9/7	1700	9.0	15.3	8.0	147	10.40	104	2	<0.1	0.01	0.67	<0.10	0.02	6	--
Issaquah Hatchery Raceway effluent	3.05	9/7	1315	9.2	14.0	8.0	129	10.55	102	2	<0.1	0.10	0.72	<0.10	0.04	4	3E
Rearing Ponds																	
Inlet	3.04	9/7	1150	--	13.9	8.0	142	10.90	105	2	<0.1	0.05	0.70	<0.10	0.02	5	--
Pond 1 outlet	3.03	9/7	1100	8J	13.9	7.9	149	9.05	87	2	<0.1	0.17	0.70	0.28	0.05	4	4E
			1100R	--	13.8	7.9	146	9.05	87	2	<0.1	0.16	0.71	0.27	0.05	6	--
Pond 2 outlet	3.03	9/7	1130	2J	14.1	8.0	143	10.95	106	1	<0.1	0.04	0.70	<0.10	0.03	5	--
Footbridge below Issaquah Hatchery	3.0	9/7	1615	19.4	15.5	8.2	139	10.20	102	1	<0.1	0.12	0.69	0.14	0.04	<4	--
			1615R	21.0	15.5	8.1	139	10.20	102	2	<0.1	0.12	0.70	0.11	0.04	5	--
Alder Ct	2.9	9/7	1510	18.8	15.3	8.2	139	10.45	104	1	<0.1	0.09	0.69	0.15	0.04	<4	--
Dogwood St	2.6	9/7	0930	15.3	13.5	8.1	143	10.55	101	1	<0.1	0.08	0.73	<0.10	0.04	5	--

J = Estimated value - not accurate.
I = Analytical interference due to salinity -- datum invalid.
R = Replicate.
E = Effluent composite value.
C = Due to inflow of mine drainage between RM 3.2 and 3.1, the latter site was considered the upstream control.

Appendix C. Macroinvertebrate community structure in three Washington streams receiving fish hatchery effluent during the summer of 1988. Organism abundance is coded as R (Rare) = 1, P (Present) = 2-4, C (Common) = 5-25, and A (Abundant) = >25. Numerals denote river miles upstream from mouth; numerals followed by "R" denote replicate samples.

	SCATTER CREEK										CINEBAR CREEK								ISSAQUAH CREEK					
TAXANOMIC GROUP	3.7	3.7R	6.4	6.4R	7.4	7.4R	8.0	8.0R	8.9	8.9R	1.3	1.3R	1.6	1.6R	1.65	1.65R	1.7	1.7R	2.6	2.6R	3.0	3.0R	3.1	3.1R
Turbellaria (flatworms)	-	-	-	-	-	-	-	-	-	-	R	P	C	C	C	C	R	P	-	-	-	-	-	-
Nematoda (roundworms)	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Hirudinea (leeches)	-	-	C	C	R	-	A	C	-	-	-	-	-	-	-	-	-	-	-	-	P	P	R	-
Oligochaeta (earthworms)	-	R	P	P	P	C	C	C	P	P	P	P	C	C	C	C	-	-	-	R	P	P	-	R
Ostracoda (seed shrimps)	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-
Isopoda (sow bugs)																								
Asellidae	-	-	-	-	-	-	C	C	-	R	-	-	-	-	R	-	-	-	-	-	-	-	-	-
Amphipoda (scuds)																								
Gammaridae	-	-	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Hydracarina (mites)	C	P	-	C	-	R	R	-	P	P	P	C	C	C	C	-	P	C	A	C	A	A	A	A
Plecoptera (stoneflies)																								
Chloroperlidae	-	-	-	-	-	-	-	-	R	-	C	-	-	C	-	-	R	C	P	C	C	C	C	C
Leuctridae	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	C	P	-	-	-	-	-	-
Nemouridae	-	R	R	C	C	A	-	-	-	-	P	P	-	-	-	P	-	-	R	R	R	R	C	P
Perlidae	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	R	-	P	P	-	R	P	P
Perlodidae	R	-	R	R	C	C	-	-	P	C	P	P	A	C	C	C	P	R	A	A	C	C	A	C
Ephemeroptera (mayflies)																								
Baetidae	A	C	A	A	A	A	A	A	A	C	A	A	A	A	A	A	C	C	A	A	A	A	A	A
Ephemerellidae	-	-	-	-	-	-	-	-	-	-	P	P	C	P	-	-	P	C	C	P	C	C	P	P
Heptageniidae	P	P	-	-	R	-	-	-	-	-	C	C	C	C	-	R	A	A	C	C	C	C	C	C
Leptophlebiidae	-	R	-	-	C	P	R	-	C	C	-	-	-	-	-	-	-	P	C	C	-	P	P	R
Siphlonuridae	-	-	-	-	-	-	-	-	-	-	-	-	C	R	-	-	-	-	-	-	-	-	-	-
Trichoptera (caddisflies)																								
Brachycentridae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	P	P	-	-	P	R
Glossosomatidae	-	-	-	-	-	P	-	-	-	-	R	-	-	-	-	-	-	-	-	-	R	C	P	-
Hydropsychidae	C	C	C	C	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Hydroptilidae	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lepidostomatidae	-	-	R	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limnephilidae	-	-	-	P	R	R	-	-	-	-	R	R	-	R	R	P	-	-	-	-	-	-	-	-
Philopotamidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-
Rhyacophilidae	-	R	P	P	-	R	-	-	-	-	C	R	C	C	P	P	P	C	C	C	C	P	C	P

Appendix C. Continued

TAXANOMIC GROUP	SCATTER CREEK 3.7	3.7R	6.4	6.4R	7.4	7.4R	8.0	8.0R	8.9	8.9R	CINEBAR CREEK 1.3	1.3R	1.6	1.6R	1.65	1.65R	1.7	1.7R	ISSAQUAH CREEK 2.6	2.6R	3.0	3.0R	3.1	3.1R
Coleoptera (beetles)																								
Dytiscidae	-	-	R	P	-	R	P	P	P	-	-	R	P	R	C	C	-	-	-	-	-	-	R	-
Elmidae	R	R	-	-	C	C	-	-	-	-	P	-	C	C	R	-	C	C	-	R	-	P	R	C
Haliplidae	P	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiptera (true bugs)																								
Corixidae	-	-	-	P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diptera (true flies)																								
Ceratopogonidae	-	-	-	R	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae	A	C	C	A	P	P	C	C	C	C	C	C	C	A	A	A	P	P	A	A	C	C	C	R
Empididae	-	-	-	-	R	-	-	-	R	-	R	-	-	-	-	-	-	-	-	-	-	R	-	-
Pelecorhynchidae	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	C	C	C	A	P	-	C	C	A	C	A	C	-	C	C	P	R	-	C	A	P	R	R	R
Tipulidae	P	R	P	C	P	C	C	C	-	-	P	P	R	P	-	R	-	R	R	-	C	C	P	P
Gastropoda (snails)																								
Ancylidae	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lymnaeidae	R	-	-	-	P	R	P	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Physidae	-	-	-	-	P	-	C	-	-	-	-	-	R	-	C	C	-	-	-	-	-	-	-	-
Planorbidae	-	-	C	-	R	R	C	C	-	-	-	R	P	C	A	A	-	-	-	-	-	-	-	-
Pelecypoda (clams)																								
Sphaeriidae	-	-	-	P	-	-	-	-	-	-	-	-	-	-	C	C	-	-	-	-	-	-	-	-